A Review of Phosphate Fertilizer Investigations in 15 Western States Through 1949

Division of Soil Management—Irrigated and Dryland Regions, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration

and

Division of Farm Management and Costs, Bureau of Agricultural Economics

In cooperation with the State Agricultural Experiment Stations of Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming.

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A Review of Phosphate Fertilizer Investigations in 15 Western States Through 1949 [1]

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INTRODUCTION

PHOSPHATE FERTILIZERS are playing a steadily increasing role in the agriculture of the West. For example, in 1939 only 37,000 tons of P_2O_5 were used in the 15 Western States covered in this review. By 1949 approximately 150,000 tons were used, representing an expenditure of about 24 million dollars.

As consumption of phosphates has increased, the economic importance of the many problems associated with phosphate use has been magnified proportionately. With the present shortage of superphosphates it is becoming increasingly important to know where, how much, and how best to apply phosphates on different crops and soils.

For nearly a half century, agricultural scientists have studied many of the phosphate problems of the West. During this period a mass of data has accumulated; however, these data have never been reviewed and summarized. It is the purpose of this circular, therefore, to review and inventory the information through 1949 and to summarize the findings.

SCOPE OF THE REVIEW

The writers have attempted to review all available published and unpublished data dealing with the use of phosphate fertilizers through 1949 in the following States:

Arizona	Idaho	Nebraska	North Dakota	Utah
California	Kansas	Nevada	Oregon	Washington
Colorado	Montana	New Mexico	South Dakota	Wyoming

[1] This review was jointly undertaken by the Division of Soil Management—Irrigated and Dryland Regions, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, and the Division of Farm Management and Costs, Bureau of Agricultural Economics, United States Department of Agriculture, in cooperation with the State Agricultural Experiment Stations of Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming.

The information was obtained by a review of literature and from consultation with specialists from experiment stations, extension services, and agricultural industries.

One of the original objectives of the project was to determine the kinds and amounts of phosphate fertilizers that could be used profitably in the Western States. It was soon apparent that the full realization of this objective was impossible. Insufficient information and heterogeneity of existing data made quantitative estimates impracticable.

The objectives of the present circular are to:

1. Summarize consumption of phosphate fertilizer by States and crops.
2. Show the nature and extent of field investigations with phosphate fertilizers.
3. Summarize the frequencies and ranges of responses to phosphate obtained by crops.
4. Compare the relative effectiveness of different phosphorus carriers and of different placements and rates of application.
5. Evaluate the residual influence of applied phosphates from one year to the next.
6. Relate, insofar as possible, observed yield responses to soils and soil properties.
7. Summarize the effect of phosphate fertilization upon the composition and quality of different crops.
8. Point out inadequacies of research information and suggest where additional research may be needed.

HISTORY OF PHOSPHATE FIELD INVESTIGATIONS IN THE WEST

Field investigations with phosphate fertilizers in the West began about 1910. For the next two or three decades, most of the trials were largely unreplicated and, according to today's knowledge, chiefly demonstrational in nature. Most were conducted on farmers' fields. The general aim apparently was to show the need for phosphate fertilizers. Very little information was gained on placements, rates, residual carryover, and comparison of sources. Only in a few instances were attempts made to relate observed yield responses with soil properties.

Since about 1940 more comprehensive types of experiments have been conducted. Greater attention has been given to replication and the relating of yield response to soils, soil properties, and plant composition. Major emphasis, for the most part, has continued to be placed upon trials of short duration.

Phosphate investigations have increased greatly since about 1948. The introduction of radioactive phosphorus techniques and regional cooperation between State and Federal agencies have been largely responsible for the recent upsurge in phosphate field investigations in much of the West.

TRENDS IN PHOSPHATE CONSUMPTION AND USE

The phosphate fertilizer consumption in the West as a whole has been increasing rapidly since 1934 (table 1). Large increases in consumption were made during the 1940's.

TABLE 1.—*Phosphate fertilizer: Consumption in West, by States, fiscal years 1934–50*

State	Average, 1934–39 (*89*)[1]	P_2O_5 consumption, year ending June 30					
		1943 (*88*)	1945 (*90*)	1947 (*134*)	1948 (*135*)	1949 (*136*)	1950 (*137*)
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
Arizona	817	2, 231	3, 346	5, 640	8, 174	8, 317	7, 256
California	13, 085	23, 136	42, 480	65, 087	58, 846	57, 796	56, 354
Colorado	992	2, 465	4, 781	6, 061	6, 970	8, 051	9, 299
Idaho	1, 741	3, 473	9, 325	9, 691	12, 567	8, 383	9, 956
Kansas	2, 450	3, 575	11, 135	15, 282	19, 719	24, 064	40, 944
Montana	1, 579	2, 098	3, 625	3, 834	3, 665	2, 913	4, 261
Nebraska	499	696	918	2, 397	2, 881	4, 717	5, 676
Nevada	85	77	68	173	206	193	236
New Mexico	652	1, 311	3, 067	3, 574	2, 311	3, 522	4, 853
North Dakota	145	899	1, 492	3, 182	6, 229	5, 352	5, 394
Oregon	2, 048	2, 965	7, 080	9, 286	11, 258	10, 812	12, 572
South Dakota	50	161	98	1, 038	2, 050	1, 835	1, 159
Utah	926	1, 248	3, 277	3, 665	3, 664	2, 012	3, 050
Washington	2, 200	5, 023	10, 944	13, 005	9, 422	10, 348	10, 411
Wyoming	779	666	1, 241	1, 464	1, 453	1, 387	1, 921
Total	28, 048	50, 024	102, 877	143, 379	149, 415	149, 702	173, 342

[1] Italic numbers in parentheses refer to Literature Cited, p. 53.

The estimated fertilizer use on major crops and the calculated amount of P_2O_5 applied per acre in 1949 for the 15 Western States are given in table 2. Sugar beets, vegetables, and potatoes have the highest per acre consumption of P_2O_5, followed by cotton, specialty crops, and fruits; pastures and grain crops have the lowest. Although the fertilizer estimates given probably differ somewhat from actual consumption, these estimates undoubtedly provide a fairly valid picture.

YIELD RESPONSE TO PHOSPHATE BY CROPS

This section reviews briefly the phosphate response by crops in the various parts of the West, and summarizes the magnitude and frequencies of the responses obtained.[2]

The graphs for each of the major crops show the frequency with which given yield responses to superphosphate have been obtained. Although these graphs show the magnitude and frequency of response for a given crop, certain limitations are involved. For example, it has not been possible to include all the data, as many were averages of groups of experiments. The data used are confounded to some

[2] Insofar as possible, the data are discussed by groups of related States as follows:

Southwestern States.—Arizona, California, New Mexico, and Nevada;
Northwestern States.—Washington, Oregon, and Idaho;
Mountain States.—Montana, Wyoming, Utah, and Colorado;
Northern Plains States.—North Dakota, South Dakota, Nebraska, and Kansas.

It is realized that State lines do not properly differentiate geographic areas, but the data were not adaptable for a more precise grouping.

TABLE 2.—*Estimated fertilizer use by crops in 1949 for 15 Western States*

Crops	Acreage [1]	Nutrient applied [2]			
		N	P_2O_5	K_2O	P_2O_5 per acre
	1,000 acres	*Tons*	*Tons*	*Tons*	*Pounds*
Corn	16, 329	11, 389	7, 116	186	0. 9
Sorghum	2, 011	1, 420	927	--------	. 9
Wheat	48, 391	21, 001	30, 792	6, 261	1. 3
Barley	7, 431	31, 731	4, 993	--------	1. 3
Oats	9, 417	2, 669	4, 078	--------	. 9
Rice	301	3, 830	15	--------	. 1
Cotton	1, 666	26, 706	7, 646	158	9. 2
Sugar beets	572	14, 502	15, 342	846	53. 6
Flaxseed	2, 827	1, 676	1, 530	--------	1. 1
Specialty crops	[2] 577	5, 183	3, 445	300	11. 9
Dry beans and peas	[2] 647	1, 345	2, 306	--------	7. 1
Potatoes	647	10, 203	10, 289	2, 039	31. 8
Vegetables	899	28, 140	22, 045	7, 885	49. 0
Fruits	[2] 1, 913	55, 146	7, 719	--------	8. 1
Hay	25, 672	2, 182	42, 860	1, 152	3. 3
Pasture	[2] 23, 831	9, 276	15, 217	324	1. 3

[1] Harvested acreage for 1949 (*170*) unless indicated otherwise.
[2] Data from reports of the Fertilizer Work Group, National Soil and Fertilizer Research Committee (*93, 94*).

extent by rate and placement variables, and sometimes by interactions with other fertilizer elements.

ALFALFA

Alfalfa is one of the more responsive crops to phosphate applications on western soils. Responses ranged from none on soils well supplied with available phosphorus to large responses on soils that were phosphorus-deficient. Greatest responses usually were obtained on irrigated lands, on which a large part of the 7,760,000 acres of alfalfa is grown. The magnitude and frequency of yield responses obtained at 270 locations are shown in figure 1. Annual responses of 1 ton per acre or more were obtained at 30.6 percent of these locations, 0.4 ton or more at 65.1 percent, and 0.19 ton or less at 23.1 percent.

SOUTHWESTERN STATES

On the Superstition sands in southern Arizona (*267*) yield responses have been large. For example, 19.9 tons of alfalfa hay were produced in 3 seasons from applications of 400 pounds of P_2O_5 per acre as compared with 8.2 tons from 100 pounds of P_2O_5. On the University Farm in the Santa Cruz Valley (*82*) equally striking responses have been reported. However, in the Salt River Valley (*256*) a study of 19 fields showed an average increase of only 0.1 ton per acre from varying rates as applied by farmers.

Responses to phosphate fertilizers have been noted at the Yuma Field Station at Bard, Calif. (*179*). A few scattered but far from conclusive responses have been observed nearby in the Imperial Valley

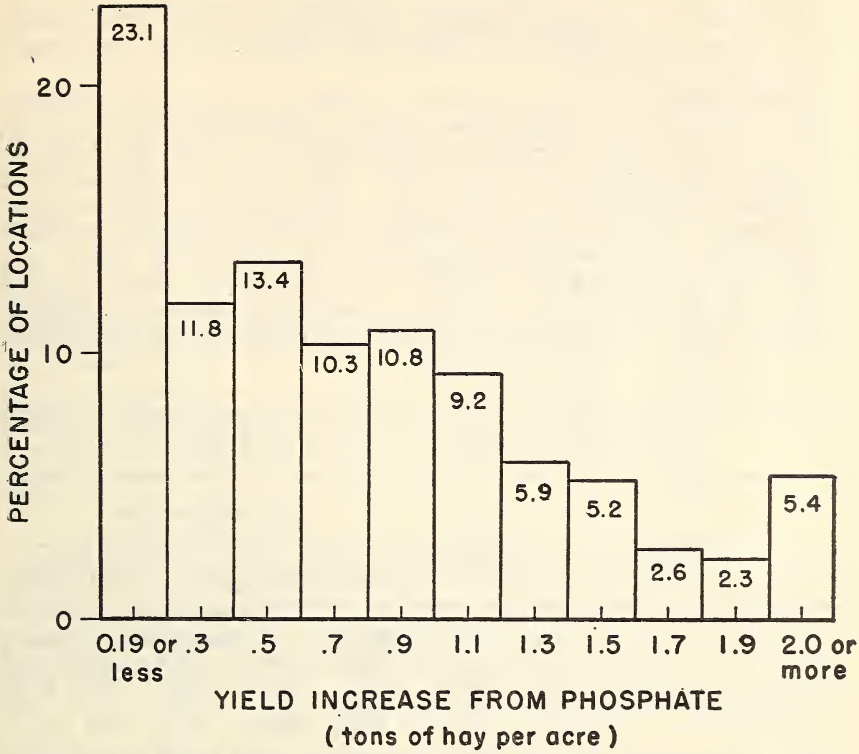

Figure 1.—Percentage distribution of alfalfa yield increases from applications of phosphate fertilizer. A summary of 270 individual experiments.

(*25, 195*). Alfalfa yields were increased about 60 percent at Las Vegas, Nev. (*48*). The yield increases from applications of 225 to 350 pounds of P_2O_5 per acre at 10 locations averaged about ¾ ton of hay per acre in the Moapa and Virgin River Valleys (*48*).

Alfalfa has responded to phosphate at Mesilla Park and at Albuquerque, N. Mex. (*52, 155, 176*). The increases at Mesilla Park on the College Farm were as high as 3 tons per acre. Other trials (*26*) in the same vicinity showed much smaller increases.

NORTHWESTERN STATES

Trials in eastern Washington (*171*) showed fairly consistent response to phosphate applications, especially in the Ellensburg district. Twenty-five trials in western Washington showed an average increase of 0.3 ton per acre from 40 pounds of P_2O_5 per acre with no further increases from higher rates (*180*). On a Sagemoor fine sandy loam at the Prosser Irrigation Station (*139*) alfalfa responded during a 9-year period to annual applications of 150 pounds of P_2O_5 per acre. Average annual yields were 4.69 tons per acre from the nonphosphated and 6.93 tons from the phosphated plots. Manure applied annually at 10 tons per acre gave increases comparable to the phosphate. In other studies near Prosser (*139, 260*) [3] similar increases in yield

[3] Personal communication from C. O. Stanberry, Washington Agricultural Experiment Station.

were obtained except on heavily manured or newly farmed land. No increase was obtained at Pasco on a newly broken Timmerman fine sandy loam (*175*).

Widespread sulfur deficiencies in Oregon frequently confound alfalfa responses to applications of single superphosphate (*119, 120, 121, 129, 133, 269*). This was particularly true in the Medford district and in the Willamette Valley. Fortunately, the importance of sulfur was realized at an early date. The effect of sulfur in superphosphates upon the yield of alfalfa is shown in table 3. Alfalfa trials (*120*) on nonirrigated land in the Grande Ronde Valley near Union, Oreg., showed no benefits from phosphate. Trials on the "red hill" soils of western Oregon frequently showed phosphate response (*133*). At Hermiston, alfalfa has responded to applications of both sulfur and phosphate (*229*).

TABLE 3.—*Effect of sulfur from several sources upon the yield of alfalfa grown near Medford, Oreg., 1915–18* (*129*)

Treatment	Rate per acre	Hay yield per plot				
		1915	1916	1917	1918	Total
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Check	--------	299	96	76	38	509
Gypsum	59. 5	1, 088	984	608	214	2, 894
Monocalcic phosphate	41. 0	318	142	94	52	606
Superphosphate	82. 3	1, 092	964	600	216	2, 872
Check	--------	216	67	66	70	419
Sulfur	10	528	1, 054	740	230	2, 552
Do	30	1, 002	1, 076	756	206	3, 040
Iron sulfate	84	1, 122	1, 156	896	272	3, 446

Alfalfa has often responded markedly to applications of phosphate at Aberdeen, Idaho, in the southeastern part of the State (*59, 68, 102, 160, 161, 226*).[4] Only slight or no response has been observed at Sandpoint in northern Idaho (*57, 59*).[4] Response only to the sulfur in superphosphate was obtained at Moscow in the Palouse section (*59*).[4]

MOUNTAIN STATES

Of 106 trials with alfalfa conducted in Montana (*42–45, 98, 99, 184*), approximately 75 percent gave responses of 0.2 ton per acre or more, and 56 percent gave 0.5 ton or more. Most of the fertilizer was broadcast on the surface at rates ranging from 45 to 90 pounds of P_2O_5 per acre. A summary of some of the trials is presented in table 4. The early Montana work is biased somewhat, as fields suspected of being deficient in phosphorus were often selected for trials.

[4] Personal communication from G. O. Baker, Idaho Agricultural Experiment Station.

TABLE 4.—*Effect of phosphate upon the yield per acre of alfalfa in irrigated valleys of Montana (98)*

County	Fields	Cuttings	Average per cutting	
			Without phosphate	With phosphate
	Number	*Number*	*Tons*	*Tons*
Gallatin	8	34	1.13	1.43
Madison	7	20	1.26	1.41
Carbon	1	3	1.11	1.58
Yellowstone	9	24	1.22	1.38
Sweet Grass	1	3	.57	.85
Stillwater	5	11	1.37	1.49
Teton	1	2	.55	1.16
Lewis and Clark	2	2	.91	.97
Missoula	1	1	.40	.65
Ravalli	4	6	.55	.62
Lake	4	4	1.00	.99

Yield data from a few trials in Wyoming showed extremely variable responses.[5] Most consistent responses in Utah occurred in the Colorado River drainage area (*41*, *113*, *114*, *115*, *268*); however, large responses were obtained elsewhere. In three trials on the Agronomy Farm at Fort Collins, Colo., no response was observed (*102*, *132*).

NORTHERN PLAINS STATES

Seventeen trials were conducted on farmers' fields in eastern North Dakota from 1924 through 1928 (*166*). Increases in yield averaged about 0.4 ton per acre from applications of 50 pounds of P_2O_5. Legume hays grown in crop rotation experiments in South Dakota showed a 0.5-ton response at Brookings but none at Cottonwood, Eureka, or Highmore (*56*).

Marked response with alfalfa has been obtained with phosphate applications on the irrigated lands of western Nebraska (*78*). Some of the response data are summarized by soil series in table 5. Trials on nonirrigated Sharpsburg silty clay loam in southeastern Nebraska showed yield increases of about 0.5 ton per acre from applications of 45 to 65 pounds of P_2O_5 per acre (*38*). A long-time study on the same soil type at Lincoln gave increases averaging about 0.25 ton per acre (*251*).

Alfalfa has responded rather consistently to phosphate applications in Kansas, especially in the eastern third of the State. At Manhattan, over a 20-year period (*159*), increases averaged about 0.25 ton. At locations elsewhere in the State (*158*) increases have been much higher (table 6). At the Thayer, Moran, and Columbus experimental fields in southeastern Kansas (*28*, *40*) phosphate increased the yield of limed plots by an average of 0.69 ton annually. Averaged data from 25 locations in southeastern Kansas in 1948 (*236*), however, indicated only a small increase.

[5] Personal communication from W. L. Quayle, Wyoming Agricultural Experiment Station.

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TABLE 5.—*The effect of phosphate upon the yield per acre of alfalfa grown on different irrigated soils in Nebraska (252)*

Soil series	Check yields	Increase from phosphate application
	Tons per acre	*Tons per acre*
Lamoure	2. 98	1. 29
Tripp	5. 22	. 54
Mitchell	3. 65	1. 67
Minatare	2. 47	1. 80

TABLE 6.—*Effect of phosphate upon alfalfa hay yields per acre in Kansas (158)*

County	Duration of experiment	Average per year		
		No phosphate	Superphosphate	Average increase
	Years	*Pounds*	*Pounds*	*Pounds*
Riley	19	4, 875	5, 445	570
Allen	9	3, 736	5, 584	1, 848
Do	4	5, 200	7, 480	2, 280
Butler	8	5, 042	6, 062	1, 020
Do	5	6, 411	8, 512	2, 101
Greenwood	5	6, 519	8, 129	1, 610
Labette	5	3, 961	6, 009	2, 048
Morris	3	4, 507	5, 913	1, 406
Wilson	4	5, 200	6, 640	1, 440
Bourbon	3	3, 540	5, 500	1, 960
Cherokee	3	4, 520	5, 500	980
Jackson	2	2, 917	4, 109	1, 192

PASTURES, GRASSES, AND OTHER HAYS

On irrigated pastures in California phosphorus deficiencies were the most widespread of the fertilizer element deficiencies (*111*). Increases in yield from phosphate applications varied considerably, with a maximum increase of 2½ times that of the check being reported in one instance. A Ladino clover-grass mixture at Corvallis, Oreg., showed striking responses to applications of phosphate (*33*). Some of the yields from this study are summarized in table 7. On an Alta fescue-legume seeding at Hermiston, Oreg., nitrogen plus phosphate was no better than nitrogen alone (*258*).

Mountain meadows occasionally have responded to phosphate. In Colorado during 1946, slightly higher yields from the use of phosphate were recorded in four of seven trials (*207*). In Utah yield increases were obtained in five out of nine trials, with the increases occurring only when a legume was present (*268*).

Crested wheatgrass, bromegrass, and Russian wildrye failed to respond to 30 pounds of P_2O_5 per acre when applied with nitrogen at Mandan, N. Dak. (*211*). Pasture grasses showed no response to phosphate at Moccasin, Mont. (*183*). Lowland meadows in the Sand Hills section of Nebraska responded to phosphate either with or without nitrogen (*249*).

TABLE 7.—*Effect of phosphate applications upon the annual yield per acre of Ladino clover-grass pasture at Corvallis, Oreg.* (*33*) (*average of 5 seasons*)

Treatment	Yield per acre	
	Green	Dry
	Tons	*Tons*
Check	11.74	2.63
300 pounds 0–16–0	23.01	4.49

SMALL GRAINS

Small grains occupy large acreages in the 15 States. Wheat is the predominating small-grain crop on dry lands of Kansas, Nebraska, and eastern Colorado, and large acreages are sown on dry lands in Montana, Oregon, Washington, Idaho, and California. Barley is grown in eastern North Dakota and South Dakota and in Nebraska, largely on nonirrigated lands. Elsewhere in the West, barley is predominantly an irrigated crop. Oats are grown mostly on the nonirrigated lands of eastern South Dakota, Nebraska, and Kansas, and in a large part of North Dakota.

Small grains, particularly wheat, showed fairly consistent responses to applications of phosphate, except where lack of moisture or nitrogen was the major limiting factor. Often, greatest responses were obtained when the phosphate was used in combination with nitrogen.

For wheat, 30.9 percent of the locations showed a response of 5 bushels or more per acre when phosphate was applied; 42.5 percent, 1 to 4.99 bushels; and 26.6 percent, less than 1 bushel (fig. 2). For oats, 35.8 percent showed a response of 10 bushels or more per acre; 43.5 percent, 2 to 9.99 bushels; and 20.7 percent, less than 2 bushels (fig. 3). For barley, 41.4 percent showed a response of 6 bushels or more per acre; 24.6 percent, 2 to 5.99 bushels; and 34 percent, less than 2 bushels per acre (fig. 4).

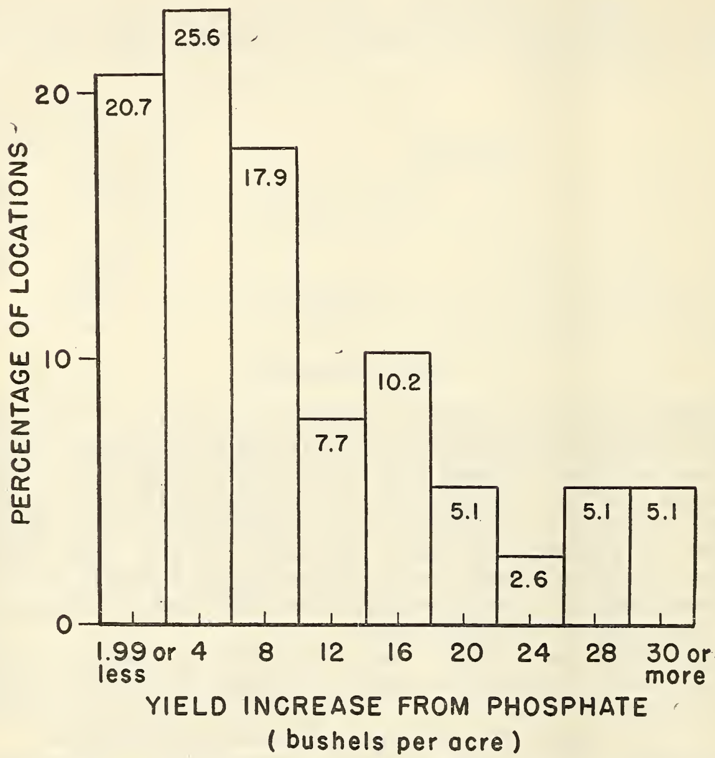

FIGURE 2.—Percentage distribution of wheat yield increases from applications of phosphate. A summary of 470 individual experiments.

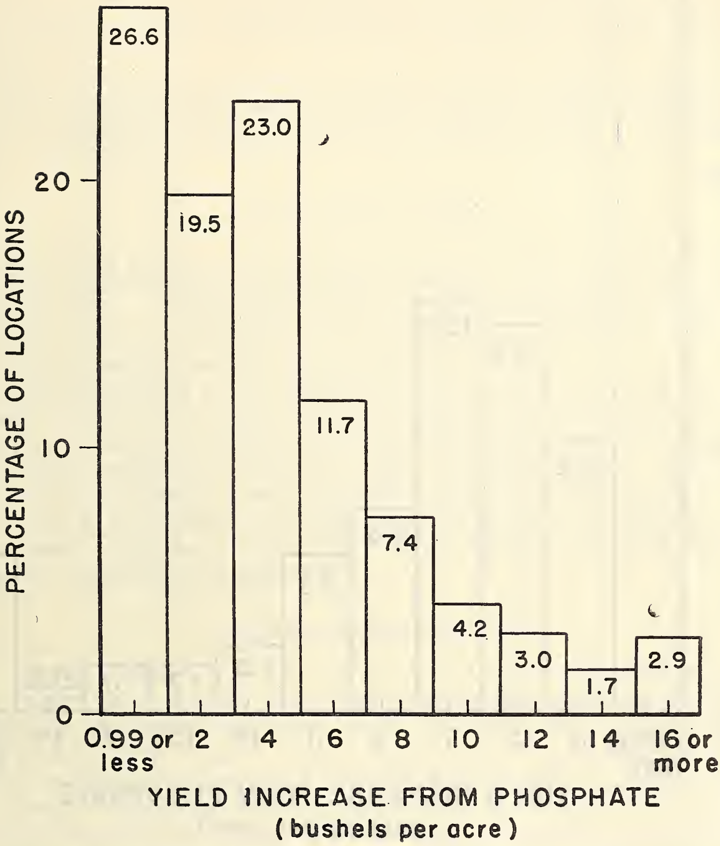

FIGURE 3.—Percentage distribution of oat yield increases from applications of phosphate. A summary of 78 individual experiments.

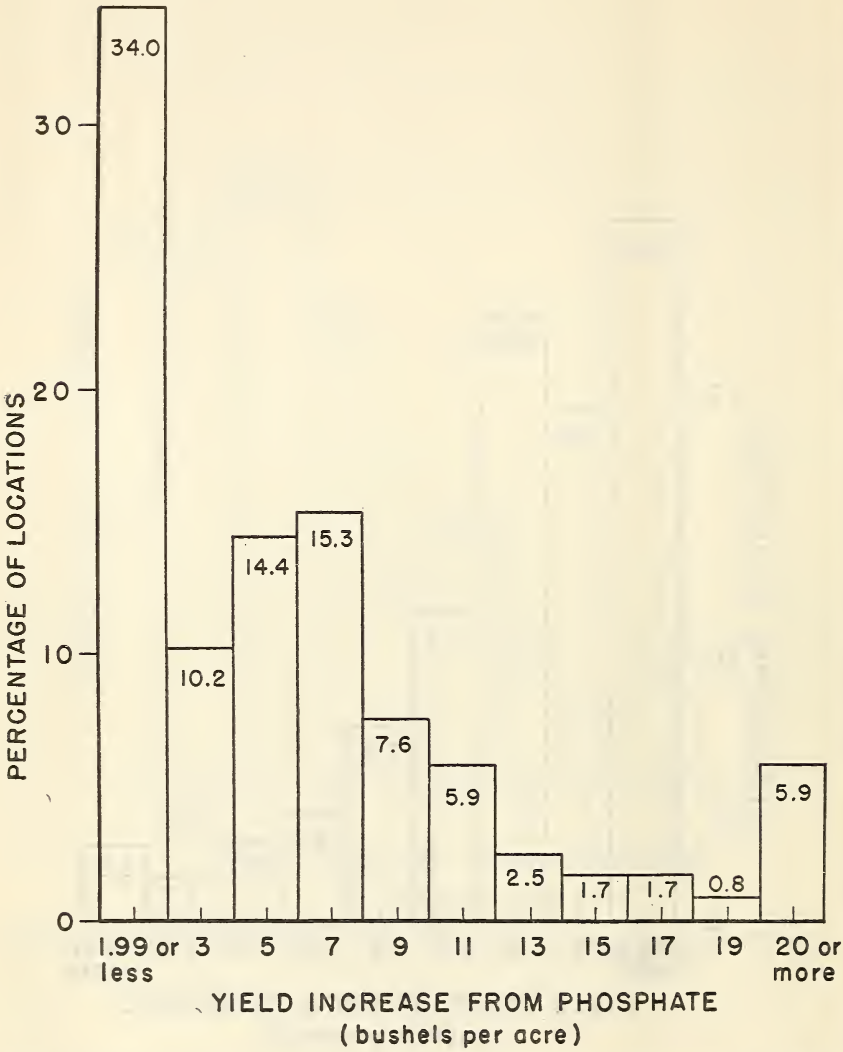

FIGURE 4.—Percentage distribution of barley yield increases from applications of phosphate. A summary of 118 individual experiments.

SOUTHWESTERN STATES

Phosphate, with nitrogen, materially increased barley yields on the Yuma Mesa in Arizona (*203*). Of 67 trials with small grains conducted on both irrigated and nonirrigated lands in California during 1948 (*232*), 25 showed a response to phosphate applications and all of these were on nonirrigated lands. Greatest response was obtained in combination with nitrogen. Rice yields were not improved materially in California (*29*).

NORTHWESTERN STATES

In a 10-year trial at Pullman, Wash., in the Palouse area, wheat failed to respond to phosphate fertilizers (*146*). Only slight increases were obtained with irrigated wheat at Prosser (*10*). Little or no benefits were noted in trials elsewhere in the State (*6*, *171*, *180*). Twenty trials with oats (*180*), mostly in western counties, showed an average increase over the yield of a nitrogen and potash check of 3.4, 6.1, 5.6, and 10.0 bushels per acre from 40, 60, 120, and 160 pounds of P_2O_5, respectively. A few early trials showed variable and seldom outstanding responses (*171*).

Wheat, in an irrigated rotation at Aberdeen, Idaho, responded to phosphate applied previously to alfalfa (*160*, *161*, *226*).[6] Wheat gave some response in Boundary County in northern Idaho, but failed to respond at Sandpoint or Moscow (*57*, *59*).[6]

MOUNTAIN STATES

Small grains grown on phosphorus-deficient fields in Montana generally have shown sizable phosphate responses (*17*, *42–45*, *91*, *98*, *99*, *184*, *185*, *246*). Wheat was grown at about 70 locations, oats at 24, and barley at 12. Most trials were on irrigated lands. Small grains have not responded on dry land at Havre.[7]

Utah reports little or no response on wheat (*115*, *156*, *192*, *268*) and variable responses on barley (*115*, *186*, *245*, *268*)[8] with phosphate applications. In the irrigated Lovelock Valley of Nevada, 2 out of 5 trials with small grains showed yield increases (*259*). Wheat responded to phosphate alone and with nitrogen in one Carson Valley, Nev., trial in 1947 (*96*). Small grains responded to phosphate at the Conservancy District Substation in New Mexico on land that had not been previously phosphated.[9]

NORTHERN PLAINS STATES

In North Dakota from 1947 through 1949, 66 trials with wheat, 4 with barley, and 3 with oats were conducted on either clean corn ground or on summer-fallowed land (*219*, *273*, *274*). The average yield increase for wheat on land fertilized with phosphate was 4.5 bushels per acre, for barley 8.9 bushels, and for oats 5.7 bushels (table 8). Some of the data indicate that phosphate response is most likely on fallow ground (*219*, *239*). Wheat has also responded to phosphate at Lankin, Park River, Jamestown, and Edgeley during 1949 (*275*). Barley has responded fairly consistently to phosphate applications, both in rotation studies (*167*, *174*) and on farmers' fields (*219*, *273*, *274*, *275*).

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[6] Personal communication from G. O. Baker, Idaho Agricultural Experiment Station.

[7] Personal communication from V. C. Hubbard, Montana Agricultural Experiment Station.

[8] Personal communication from H. B. Peterson, Utah Agricultural Experiment Station.

[9] Personal communication from H. D. Jones, New Mexico Agricultural Experiment Station.

TABLE 8.—*Effect of phosphate upon the yield per acre of small grains in North Dakota, 1947–49 (219, 273, 274)*

Crop and section of State	Trials	Average yields	
		No phosphate	Phosphate [1]
	Number	*Bushels*	*Bushels*
Durum wheat	14	24. 9	30. 7
Wheat (hard):			
Western counties	13	22. 0	26. 2
Central counties	23	21. 3	26. 0
Valley counties	16	26. 3	29. 6
Barley	4	35. 6	44. 5
Oats	3	45. 6	51. 3

[1] Usually 20 to 25 pounds of P_2O_5 per acre was applied either with a fertilizer attachment or mixed with the seed.

South Dakota data indicate that wheat seldom responded to phosphate application on nonirrigated land (*55, 56, 126, 188, 189, 190, 248*).[10] In 4 trials on farmers' fields responses averaged 4 bushels (*126*). Limited data, however, indicate that barley responded to phosphate (*55, 56, 126, 190, 248*). At 10 locations the average oat yield increase was 4.5 bushels from phosphate, 9.6 bushels from nitrogen, and 18.1 bushels from the combination of phosphate and nitrogen (*126*). Oats at 3 locations in 1949 showed an average increase of 10.4 bushels from 20 pounds of P_2O_5 per acre and 14.7 bushels from nitrogen and phosphate together (*248*). In long-time rotations (*56*), responses were obtained on wheat, barley, and oats at Brookings but not at Cottonwood, Eureka, and Highmore.

Small grains on nonirrigated lands in Nebraska (*206, 234, 272*) usually showed response to phosphate fertilizer (table 9). Winter wheat has responded consistently to phosphate, particularly when accompanied by spring topdressings of nitrogen (*213, 242*). As shown in table 10, wheat responses to the fertilizer are greatest in the eastern part of the State (*253*). Oats (*37, 214, 234, 257, 272*) gave a response of 4 bushels or more per acre at 5 out of 16 locations. Barley shows greater response on the irrigated lands of western Nebraska than on the nonirrigated lands elsewhere in the State. For example, irrigated barley on fields not previously phosphated showed positive response in 9 out of 10 trials (*78*). The increases ranged from −1.0 to 49.9 bushels per acre, with a mean of 17.6 bushels. Nonirrigated barley (*38, 205, 214, 234, 272*) showed a response of 4 bushels or more per acre at 9 out of 30 locations, mostly in the eastern part of the State.

Numerous trials with nonirrigated wheat have been reported in Kansas (*28, 130, 143–145, 158, 159, 198–200, 204, 221–223, 236*).[11]

[10] Personal communication from L. O. Fine, South Dakota Agricultural Experiment Station.

[11] Personal communication from A. L. Clapp, Kansas Agricultural Experiment Station.

TABLE 9.—*Some average yields of small grains on phosphated and nonphosphated plots on nonirrigated lands in Nebraska, 1938–42 (206, 234, 272)*

Crop and year	Trials	Average per acre	
		No phosphate	Phosphate
	Number	*Bushels*	*Bushels*
Wheat:			
1938	21	17. 5	21. 0
1939	20	16. 0	20. 7
1940	94	24. 3	27. 3
1941	7	11. 2	20. 1
1942	29	29. 4	35. 1
Barley:			
1938	6	32. 7	40. 7
1939	5	12. 8	12. 8
1940	5	27. 7	31. 1
Oats:			
1938	2	45. 8	43. 9
1939	4	18. 3	22. 5
1940	4	34. 3	40. 0

TABLE 10.—*Effect of fertilizers on the yield of nonirrigated wheat in various sections of Nebraska during 1948 (253)*

Section of State	Check yield per acre	Yield increase per acre from indicated proportion of N–P_2O_5–K_2O		
		0–30–0	40–0–0	40–30–0
	Bushels	*Bushels*	*Bushels*	*Bushels*
Eastern	22. 9	1. 3	12. 5	19. 6
South central	35. 0	–. 4	8. 3	8. 4
Western [1]	42. 5	1. 1	. 5	. 6

[1] On summer-fallowed land.

An average response of 3.5 bushels per acre was obtained from 254 trials conducted from 1931 to 1938.[11] At Manhattan in 1947 (*143*) either phosphate or nitrogen applications alone failed to increase wheat yields; however, a combination of 25 pounds of P_2O_5 placed with the seed and 25 pounds of nitrogen placed either with the seed or topdressed resulted in a significant increase. At 4 locations in eastern Kansas during 1948 (*198*), yield increases ranged from 0 to 9 bushels per acre. At 3 of 4 locations during the same year, also in eastern Kansas (*145*), wheat responded both to phosphate and to nitrogen plus phosphate. In 24 trials in 1949 (*199*) wheat responded to applications of phosphate in both the eastern and central sections of the State but not in the western section (table 11).

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TABLE 11.—*Response of wheat to phosphate in different sections of Kansas during 1949 (199)*

Section of State	Trials	Yield per acre	
		No phosphate	Phosphate [1]
	Number	*Bushels*	*Bushels*
Eastern	13	24. 2	27. 8
Central	6	13. 2	17. 7
Western	5	17. 0	16. 5

[1] Phosphate applied with seed at rate of 25 pounds of P_2O_5 per acre.

In central Kansas during 1949, six other trials with wheat showed yield increases with phosphate used alone ranging from 0 to 16.6 bushels per acre, with a mean of 6.4 bushels per acre (*200*). A long-term rotation experiment at Manhattan with Turkey, Tenmarq, and Quivera varieties showed annual increases averaging about 8 bushels per acre (*130*). There were no differences in response between the varieties. Oats responded rather consistently in several trials reported (*28, 197, 204, 222, 223*).

CORN

Most of the 16 million acres of corn grown in the 15 States are on the nonirrigated lands of the Great Plains. Nebraska grows about half the total acreage, followed in turn by South Dakota, Kansas, North Dakota, Colorado, and Montana.

Corn seldom responded to phosphate, although some exceptions were noted. The frequency distribution of responses from 80 trials are shown in figure 5. Of these trials, 11.1 percent gave responses of 11 bushels per acre or more; 33.8 percent, 1 to 4.9 bushels; and 45.0 percent, less than 1 bushel. Very little phosphate is applied for corn, averaging only 0.9 pound of P_2O_5 per acre in 1949.

Scattered early trials in Washington showed occasional increases in corn grain and silage yields from phosphate applications (*171*). On irrigated Sagemoor soil at Prosser, corn yields were increased in some years but not in others (*140*).[12] Four of eight trials with corn silage in western Washington showed response (*180*). Seven trials on irrigated Sagemoor fine sandy loam in Yakima County during 1938 and 1939 showed response when phosphate was applied as a supplement to 6 tons of manure per acre (*32*). In these trials, 8 pounds of P_2O_5 applied with each ton of manure resulted in a 17-bushel yield increase over that from manure alone.

Corn has responded rather consistently to phosphate applications in rotation studies at Fargo, N. Dak. (*63, 154, 167, 174, 238, 240, 275*). Trials in Utah (*192, 268*) and in Oregon (*118, 120–122, 133, 241*) showed no responses.

[12] Personal communication from C. O. Stanberry, Washington Agricultural Experiment Station.

In South Dakota (*55, 56, 126, 188–190, 247*)[13] responses generally were small, although a few were substantial. In long-term rotation trials at 4 locations (*56*), response to phosphate applications was obtained only at Brookings, where the increase averaged 4.7 bushels per acre. In 15 trials on farmers' fields from 1944 through 1946, the average yield response to phosphate was 8.1 bushels per acre, to nitrogen 6.3 bushels, and to nitrogen and phosphate 9.2 bushels (*126*). On a subsoil exposed by leveling for irrigation, corn responded markedly to phosphate in the presence of nitrogen (*190*).

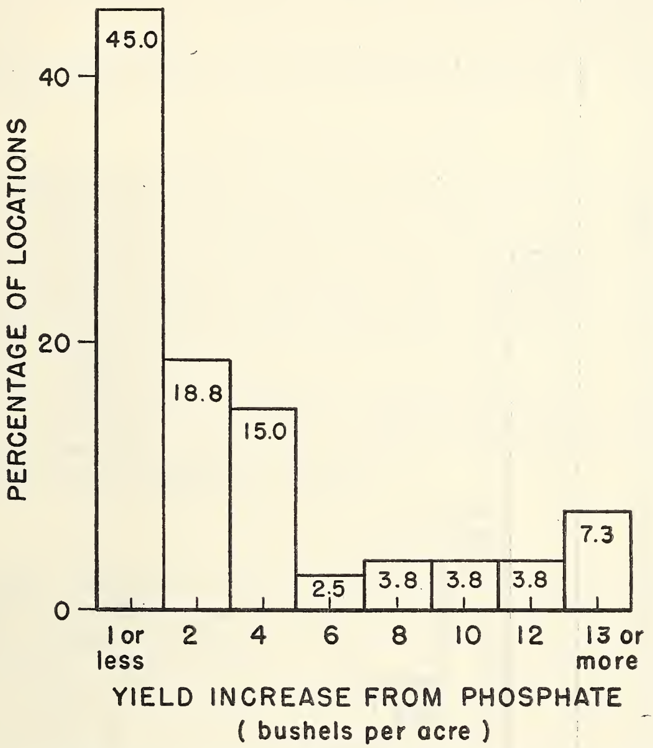

Figure 5.—Percentage distribution of corn yield increases from applications of phosphate. A summary of 80 individual experiments.

Corn in Nebraska has shown little or no benefits from phosphate on either irrigated or nonirrigated land (*37, 38, 205, 231, 257*). Sometimes, phosphate reduced the yield. Data from Kansas (*112, 128, 145, 158, 159, 201, 236*) indicated little or no response, although there were a few isolated exceptions.

Sugar Beets

Sugar beets are grown commercially in all 15 States; however, the area seldom exceeds 600,000 acres in any one year. As a rule, beet

[13] Personal communication from L. O. Fine, South Dakota Agricultural Experiment Station.

fields are well fertilized; in 1949 approximately 54 pounds of P_2O_5 was applied per acre. This is one crop that is limited almost entirely to irrigated lands.

Sugar beets frequently respond to phosphate. Within any locality, however, the response is extremely variable. The frequency and magnitude of responses at 173 locations are shown in figure 6. Of these, 11.0 percent showed a response of 5 tons or more per acre, 54.4 percent from 1 to 4.99 tons, and 34.6 percent less than 1 ton.

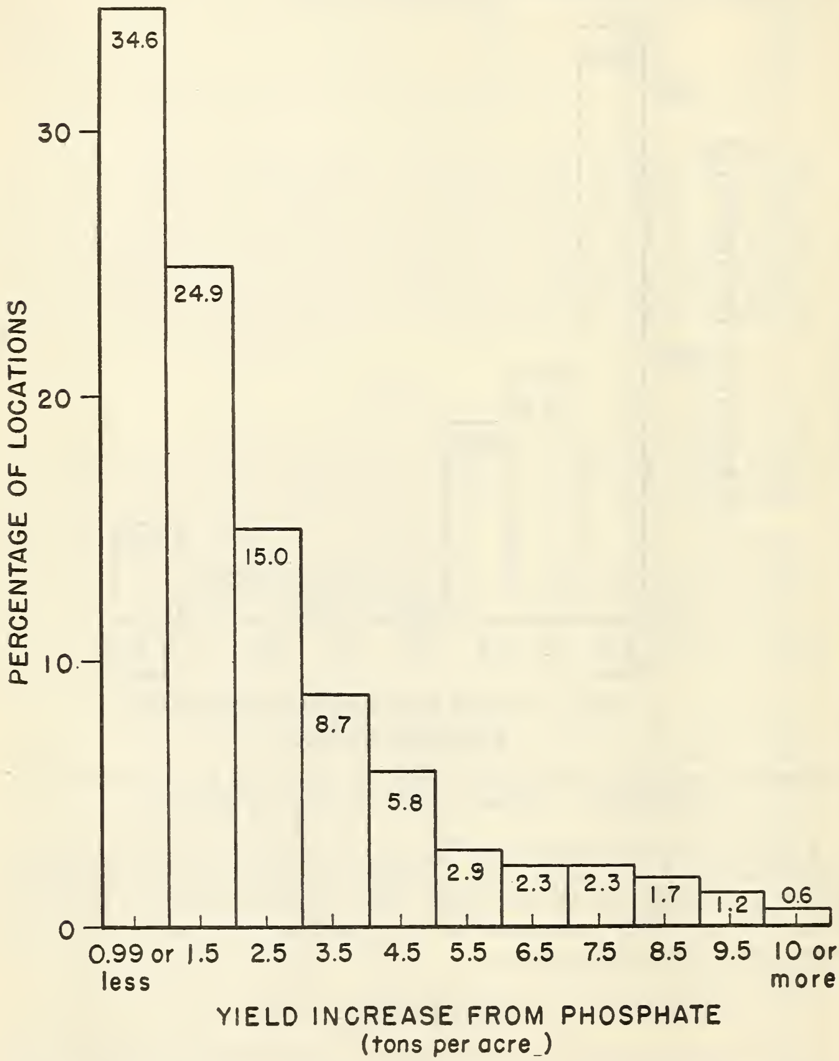

FIGURE 6.—Percentage distribution of sugar beet yield increases from applications of phosphate. A summary of 173 individual experiments.

SOUTHWESTERN STATES

Several experiments were conducted in California during 1939 and 1940 on mineral soils in the Sacramento Valley and on peat and muck soils of the Sacramento-San Joaquin Delta (*110*). None of the beets grown on strictly mineral soils responded to phosphate applications. On strongly acid soils of the Ryde series, which are intermediate between true mineral and peat soils, yields were much improved through the use of phosphate. Beets grown on the muck and peat soils, such as the Egbert, Staten, and Venice, showed no benefit from phosphate.

Sugar beet seed yields appeared to have been slightly increased in New Mexico (*107*) but not in the Willamette Valley or at Medford, Oreg. (*109*).

NORTHWESTERN STATES

In Washington, on irrigated lands from 1945 through 1947 (*64, 162, 164*), no yield trends for sugar beets were discernible in 21 trials. In a few instances, however, applications of nitrogen and phosphate combinations were more effective than nitrogen alone. In 3 trials on Puget silt loam in western Washington (*180*) sugar beets responded to nitrogen and potash but not to phosphate. Little or no response was obtained on newly irrigated lands at Prosser, Pasco, and Moses Lake during 1948 (*175*).

In Idaho responses to phosphate applications again have been inconsistent (*62, 64, 142, 162, 164*). The lack of consistent responses with sugar beets was believed the result of variable applications of farm manures and phosphate fertilizers.

MOUNTAIN STATES

Beet-yield response to phosphate had been observed frequently in Montana (*1, 17, 42, 64, 91, 95, 98, 99, 117, 164, 184, 185, 187, 262*). Response appeared extremely variable at Torrington and in the Big Horn Basin in Wyoming (*95, 97, 127, 191*). Some responses were noted in Utah (*47, 62, 64, 115, 156, 164, 192*). Most increases ranged from 0.5 to 1.5 tons per acre and a few from 4 to 5 tons.

Varied yield response of sugar beets to phosphate applications was noted in Colorado (*24, 30, 31, 39, 45, 95, 141, 153, 181, 182*). In the Berthoud and Wellington districts (*153*) studies conducted from 1929 through 1931 showed positive response in 7 out of 12 locations. Trials conducted in the Arkansas Valley for many years usually showed increases in yield from phosphate (*54, 101, 141*). On the Agronomy Farm at Fort Collins (*39*) beets grown during 1942 and 1944 responded to 5,000 pounds of treble superphosphate per acre applied in 1935. On the same farm (*181, 182*) beets responded to phosphate applied on land where the topsoil had been removed by leveling. In northeastern Colorado 37 trials conducted in 1947 showed an average increase of 0.56 ton, although much larger increases were obtained on some farms (*95*).

NORTHERN PLAINS STATES

In western South Dakota beets on some farms responded only to phosphate applications, some only to nitrogen, while others responded to both (*162, 164, 262*).

In the irrigated areas of Nebraska beets have shown fairly consistent response to phosphate (*37, 78, 95, 205, 220, 250, 252, 255*). Some typical responses on different soils are shown in table 12. Beets grown on the calcareous Minatare soil have been particularly responsive (*252*). In 51 trials (*78*) large yield increases were obtained on the low-yielding fields (table 13).

TABLE 12.—*Effect of phosphate upon the yield per acre of beets grown on various soils in Nebraska* (*252*)

Soil series	Check plot	Increase from phosphated plot
	Tons	*Tons*
Hall and Holdrege	17. 00	0. 20
Tripp	14. 70	. 70
Mitchell and Bridgeport	12. 60	1. 93
Minatare	6. 20	6. 80

TABLE 13.—*Effect of phosphate upon the yield per acre of sugar beets from fields having different levels of productivity, Nebraska, 1930–38* (*78*)

Yield range of checks (tons per acre)	Average	
	Nonphosphated plots	Phosphated plots
	Tons	*Tons*
Less than 5	3. 8	13. 0
5 to 9.9	7. 9	13. 0
10 to 14.9	13. 0	15. 0
More than 14.9	17. 5	18. 6

POTATOES

About 647,000 acres of potatoes were grown in the 15 States in 1949, with the largest acreages in Idaho and North Dakota. Approximately 10,300 tons of P_2O_5 were applied on potatoes in 1949, or about 32 pounds of P_2O_5 per acre. Potatoes usually fail to show consistent responses to phosphate. The frequency distribution for 190 trials showed that 29.8 percent with increases of 25 hundredweight or more, 45.8 percent of 5 to 24.9 hundredweight, and 24.4 percent with less than 5 hundredweight (fig. 7).

Potatoes in Kern and San Joaquin Counties in California (*76, 77, 235, 266*) showed only slight yield increases from applications of

phosphate. Data from trials in the subirrigated San Luis Valley of Colorado showed a wide variation in response from farm to farm (*84, 147, 227*). In these trials, rates ranged from 40 to 240 pounds of P_2O_5 per acre and responses of 10 sacks of potatoes or more per acre were frequently obtained.

Yield responses in western Washington have been extremely variable. Average yield data from one series of 34 trials indicated no response (*180*).

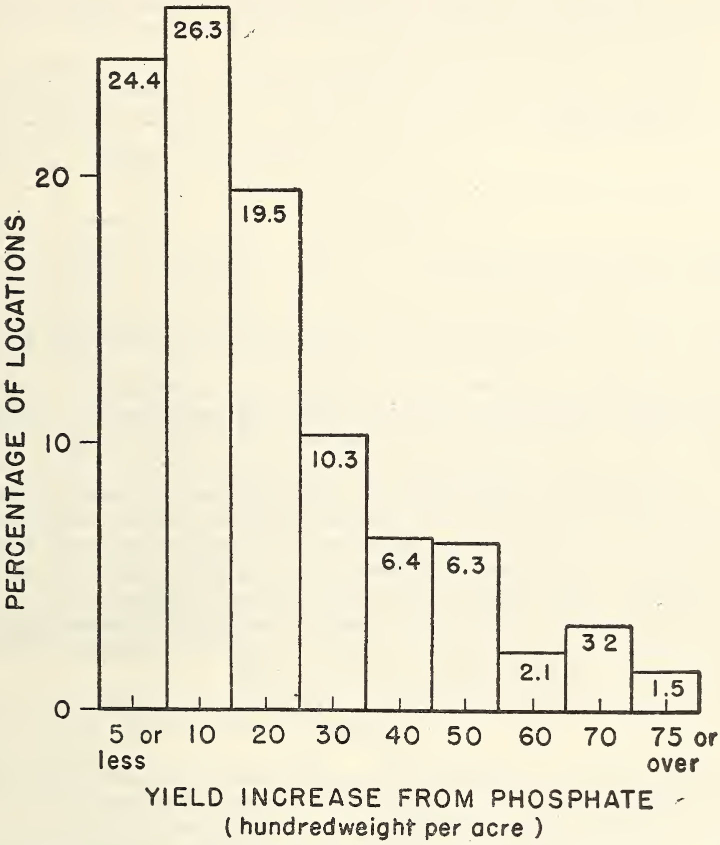

FIGURE 7.—Percentage distribution of potato yield increases from phosphate. A summary of 190 individual experiments.

Several experiments with potatoes were conducted on Parkdale loam in the Hood River Valley, Oreg., during the period 1920–30 (*13*). Usually there was no response from phosphate, nitrogen, or potash alone. Combinations of nitrogen and phosphate were quite effective.

In southern Idaho fairly consistent responses have been obtained from phosphate fertilizers (*67*). At Aberdeen potatoes have responded considerably to phosphate applied on alfalfa in a rotation

(*160*).[14] Generally, potatoes immediately following phosphated alfalfa have not responded to additional phosphate. During the period 1935–44 numerous demonstrational trials were conducted in 18 southern counties (*69*). The crop responded to applications of phosphate, nitrogen, and to combinations of them (table 14). The average response was greater on farms where potatoes followed a nonlegume crop. At Sandpoint in northern Idaho (*57*)[14] potatoes have shown very little, if any, response to phosphate.

TABLE 14.—*Effect of nitrogen and phosphate upon the yields of potatoes after legume and nonlegume crops in Idaho* (*69*)

Treatment[1]	After legume crop		After nonlegume crop	
	Farms	Increase	Farms	Increase
	Number	*Cwt.*	*Number*	*Cwt.*
N	31	13. 8	40	22. 4
P	93	18. 3	85	23. 2
N+P	35	26. 9	42	28. 2

[1] Average rates per acre: 175 pounds ammonium sulfate and 175 pounds treble superphosphate.

Potatoes grown on the Station Farm at Bozeman, Mont., and on farmers' fields elsewhere in the State have responded fairly consistently to applications of phosphate (*50*). In rotation trials at Fargo, N. Dak., potatoes apparently were benefited from phosphate (*174, 238*). Nine cooperative trials in South Dakota (*126*) showed a 55-bushel-per-acre average yield increase from 42 pounds of P_2O_5, and the further addition of 20 pounds of nitrogen increased the yield another 10 bushels. Wyoming, on the other hand, obtained no yield increases over a 10-year period in trials conducted at Laramie and Torrington.[15]

In Nebraska, the data from trials on irrigated land have shown variable and far from conclusive responses (*78, 218, 252, 254*). Kansas (*22*) has reported no increase in potato yields.

COTTON

During 1949 an average of 9.2 pounds of P_2O_5 per acre was applied to 1,666,000 acres of cotton grown in Arizona, California, and New Mexico. Cotton appears to respond only slightly to phosphate applications. For example, Arizona data (*80, 138, 208, 209*) indicated that cotton seldom responds to applications of phosphate, but there were exceptions. A trial on the Nichols Ranch in Santa Cruz Valley in 1941 (*80*) gave a yield increase of about 260 pounds of cotton per acre from 200 pounds of treble superphosphate. On the Mesa Farm (*208, 209*) phosphate increased the yields of the first picking, but this benefit was nullified by later pickings. The use of 300 to 600 pounds per acre of treble superphosphate increased the yield of seed cotton about 250 pounds per acre on land that had been in cotton for a num-

[14] Personal communication from G. O. Baker, Idaho Agricultural Experiment Station.

[15] Personal communication from W. A. Riedl, Wyoming Agricultural Experiment Station.

ber of years. In a series of experiments conducted from 1920 to 1928 in the Salt River Valley (*138*), where 250 to 1,000 pounds per acre of double superphosphate was applied broadcast and harrowed into the soil, only slight or no response was obtained from either phosphate applied alone or in combination with nitrogen.

Cotton has shown small but consistent responses to phosphate in New Mexico (*26, 53, 151, 216*). An average increase of 0.396 pound of lint cotton per pound of applied phosphate was obtained from a number of trials in which phosphate alone was applied (*151*). Studies in New Mexico indicated that if phosphate has been applied to alfalfa ahead of the cotton crop, the cotton probably would not benefit from additional phosphate. As a result of high cotton prices in recent years, the acreage of cotton in the Mesilla Valley has been increased and alfalfa greatly decreased. This situation has resulted in the general recommendation that 40 pounds of phosphate and 60 to 100 pounds of nitrogen per acre be applied.[16]

Truck Crops

Approximately 899,000 acres of truck crops were grown in the 15 States during 1949, of which 58 percent of the acreage was in California. Truck crops require a high investment per acre and consequently are heavily fertilized. For example, 49 pounds of P_2O_5 per acre were applied in 1949. Some truck crops in the West showed large yield increases from phosphate, although the increases have been extremely variable. This variability probably resulted from differentials in past fertilization and in the season of the year when the crops are grown.

Lettuce in Arizona has frequently responded to phosphate. Trials conducted as early as 1922 and 1923 (*27*) showed increases in head weight, often amounting to 20 pounds per 100 heads. In later trials (*46, 80, 83*) yield increases of 10 crates or more per acre were reported. While some response was obtained from phosphate used alone, a greater response was usually obtained from a combination of nitrogen and phosphate (*83*), as indicated in table 15.

Table 15.—*Effect of fertilizers upon the yield in crates per acre and head size of lettuce grown at the Mesa Experimental Farm in Arizona during 1939* (*83*)

Treatment	4-dozen size	5-dozen size	6-dozen size	Total
	Crates	*Crates*	*Crates*	*Crates*
No fertilizer	0	2	11	13
0–48–0 band [1]	0	20	46	66
$CaNO_3$ side dressing [2]	0	17	25	42
0–48–0 band, $CaNO_3$ side dressing	59	112	39	210
11–48–0 side dressing [3]	65	134	27	226

[1] 144 pounds of P_2O_5 per acre.
[2] 46.5 pounds of N per acre.
[3] 33 pounds of N and 144 pounds of P_2O_5 per acre.

[16] Personal communication from Glen Staten, New Mexico Agricultural Experiment Station.

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In California (*230*)[17] the response of vegetable crops to phosphate application has varied from location to location and from season to season. Variation in previous use of fertilizers undoubtedly is a contributing factor. Also, fast-growing vegetables grown during the cool winter months are most likely to respond (*217*).

Most truck crops in Nevada are benefited from phosphate (*243*, *244*). It has been noted from limited trials in New Mexico that cabbage responded (*36*), that onion response was variable (*35*), and that there was little or no response with most other vegetable crops when phosphate was applied.[18]

Many trials with peas for canning and freezing in Washington (*7–10*, *171*, *180*) have shown that the addition of phosphate usually increased the yields. When applied with nitrogen, phosphate increased both yield and earliness of lettuce (*23*).

Tree Crops

Experimental data showing definite yield response of tree crops to phosphate are almost nonexistent. Nevertheless, considerable phosphate is applied; for example, in 1949 a total of 7,719 tons of P_2O_5 was applied on the 1,913,000 acres planted to tree crops, or about 8 pounds of P_2O_5 per acre.

The yield of grapefruit in Arizona was not increased when phosphate was used (*34*). The yields of pears (*123*, *124*), prunes (*124*, *125*), apricots (*124*, *125*), peaches (*71*, *124*, *125*), apples (*71*), oranges (*18*, *108*), and lemons (*4*) were not increased in California. Trials on phosphorus-deficient Aiken soils (*75*) showed that phosphate applications increased the yields of 18 annual crops but did not affect fruit yields.

Phosphate frequently increased vegetative growth. For example, trials with peaches on the Aiken soil (*72*, *73*) showed that superphosphate applied in the bottom of the hole at planting time markedly increased the growth during the first year and, to a somewhat lesser extent, during the second and third years. In recent trials with lemons (*4*) phosphorus injections into the tree resulted in large vegetative response. Evidence based on leaf analysis (*21*) indicated that some citrus orchards may have suffered from a mild phosphorus deficiency.

Jenny and collaborators (*61, p. 61*) offered the following explanation for lack of response by tree crops:

> The exact reason for the differential behaviour of trees and annual crops is not fully understood. On an acre basis, the phosphate removal by an average crop of oranges plus that required for the production of the annual new growth of trees is not greatly different from that removed by small grain, corn, clover, and potatoes. But whereas the annual crops must obtain their phosphates in a growing period of from 2 to 4 months, citrus trees probably absorb phosphate continuously throughout the year. Similarly, the root activity of deciduous fruit trees under California conditions appears to continue throughout the winter.

There has been a lack of response to phosphate applications by fruits and nuts in Oregon (*152*), although the growth of mixed barley and vetch cover crops in the orchards may have been improved.

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[17] Personal communication from O. A. Lorenz, California Agricultural Experiment Station.

[18] Personal communication from J. V. Enzie, New Mexico Agricultural Experiment Station.

Applications of phosphate failed to increase yields of pears (*103*) and apples (*66, 92, 104*) in Washington, apples and prunes (*168*) in Idaho, and cherries (*157*) and peaches (*149*) in Utah.

In Colorado sour cherries have not responded to phosphate either alone or in combination with nitrogen (*14, 16*). Peach yields in Mesa County (*194*) were apparently increased about 10 percent. Superphosphate applied in the root zone to pear trees in Mesa County (*15*) overcame phosphorus-deficiency symptoms.

Fruits have not responded to phosphate in Kansas,[19] although cover crops grown in the orchards were benefited.

RELATION OF PHOSPHATE RESPONSE TO SOILS

Some attempts have been made to relate observed phosphate responses to soil types, soil properties including available soil phosphorus, and to previous soil and crop management practices. Although some of the data are encouraging, much still remains to be accomplished before observed yield responses can be clearly interpreted in relation to soils and soil conditions.

SOUTHWESTERN STATES

Data from Arizona show little direct correlation between phosphate fertilizer needs and soil type. For example, an attempt (*256*) was made to relate phosphorus response of alfalfa to soil type, but definite conclusions could not be drawn, because of too few observations for each soil type. Superstition sands on the Yuma Mesa, however, appeared extremely deficient in available phosphorus (*267*). Some data from Arizona indicated fairly good correlation between the CO_2-soluble phosphorus content of the soil and crop response (*5, 79, 80, 83, 267*). McGeorge (*81*) also has pointed out certain general relationships between phosphate fertilizer use and the properties of Arizona soils.

In a few trials in California crop response was correlated with soil types. Sugar beets in the Sacramento Valley and on the Sacramento-San Joaquin Delta (*110*) gave no response to phosphate on the strictly mineral soils, marked response on the strongly acid soils of the Ryde series, which are intermediate between true mineral and peat soils, and no response on the true peat soils such as Egbert, Staten, and Venice.

Sugar beet petiole samples were analyzed from 37 fields in California during 1943 (*263*). Attempts were made to select one field of average fertility or above and one of below average in each sugar beet district. Chemical analysis of the petioles indicated that 6 fields had adequate nitrogen and 22 adequate phosphorus. Beet yields ranged from 6.6 to 33.7 tons per acre; however, the observed yields could not be correlated with soil type, previous soil management, or other factors. A similar study was made during 1944 (*264*), and the findings were much the same.

Considerable greenhouse work has been done in California (*60, 61*) in an effort to classify the soils according to their available phos-

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[19] Personal communication from W. F. Pickett, Kansas Agricultural Experiment Station.

phorus content. The results of the greenhouse investigations for five groups of soils indicated that low phosphorus levels were widespread (table 16). Soils of the Aiken series, found in the hills and mountains and developed from basic igneous rocks, have shown a definite tendency of phosphorus deficiency (*60, 72, 75*). In contrast, the recent alluvial soils were somewhat better supplied with available phosphorus. Soils that have a pronounced acid or alkaline reaction tend to be low in available phosphorus (*60*) (table 17).

TABLE 16.—*Percentage of various California soils having low or high levels of available phosphorus as determined in greenhouse studies* (*60*)

Soil group	Soils tested	Soils tested that were—	
		Low in available phosphorus	High in available phosphorus
	Number	*Percent*	*Percent*
Recent alluvial	137	38	52
Older alluvial	91	42	52
Claypan	65	71	23
Hardpan	27	74	11
Hills and mountains	110	67	24

TABLE 17.—*Relationship between soil pH and available phosphorus in California soils* (*60*)

Soil reaction groups, pH	Soils tested	Soils that were low in available phosphorus
	Number	*Percent*
Below 5.9	105	79
6.0–6.3	91	65
6.4–6.7	89	37
6.8–7.9	116	26
8.0–8.3	27	44
Greater than 8.3	20	80

There are definite indications that most of the irrigated soils in the southern part of Nevada are phosphorus-deficient (*48, 96, 243, 244, 259*). Clay loams of the Rio Grande Valley in New Mexico have been found deficient in phosphorus (*176*). Soil tests indicated the existence of frequent phosphorus deficiencies throughout New Mexico.[20] About one-third of the samples submitted from the Tucumcari irrigation project in northwestern New Mexico were found low in available phosphorus (*196*).

[20] Personal communication from H. E. Dregne, New Mexico Agricultural Experiment Station.

Northwestern States

In Oregon, response by crops to phosphorus has been noted on the acid (pH 5.0 to pH 6.0) "red hill" soils of the western part of the State (*133*), particularly on the old grain-farmed lands (*122*); on some soils of the coast area and the Willamette Valley (*121*); on the soils of the Grande Ronde Valley (*120*); and at Hermiston (*118, 269*). Response to sulfur was noted on the basaltic soils of the State (*122*), particularly around Medford and in the Willamette Valley.

As the results of a survey of the organic and inorganic phosphorus contents in western Oregon soils (*12, p. 225*), the following statement was made:

> The total phosphorus content of the soils according to groups was: Mature valley soils >recent stream-bottom soils >old residual hill soils. The percentage organic of the total phosphorus in these soils by groups was: Old residual hill soils >mature valley soils >recent stream-bottom soils. In general, the phosphorus fertility or supplying power of these soils is in an inverse order to that of the organic phosphorus percentage of the total phosphorus.

In a recent study[21] the available phosphorus content of several typical Oregon soils was determined by the Truog method. The data showed the Melbourne and Olympic soils were low in available phosphorus as compared with the Chehalis and Willamette soils. Absorbed phosphorus studies showed a similar relationship.

Attempts have been made in Washington (*32, 171, 180*) to relate field response of crops to soil types and soil characteristics. The data showed an extreme variation in response to phosphate fertilizer both between and within soil types. With the exception of the Felida soils formed on old terraces, the acid soils of western Washington were generally deficient in phosphorus. Irrigated soils of central Washington (*139, 175*)[22] appeared to be initially well supplied with available phosphorus and did not require phosphate until they had been cropped for a number of years. Applications of farm manure usually eliminated the need for fertilizer phosphorus. Dryland soils in eastern Washington (*146, 180*) usually showed no need for phosphate. Soil tests on 300 samples from 125 different orchards[23] indicated that only 3 percent of the samples might have been considered low in phosphorus for such annual crops as tomatoes.

In Idaho, greatest response of crops to phosphate applications was obtained on the calcareous soils in the southern part of the State (*59, 68, 102, 160, 161, 226*),[24] and smallest response on the acid timber soil and Chernozem soils in the northern part of the State (*57, 59*).[24]

Mountain States

In early trials in Montana (*17, 42–45, 98, 99, 184, 185*) no attempt was made to relate crop response to soil type. The Winogradsky test was used for several years to measure the available phosphorus

[21] Personal communication from W. L. Powers, Oregon Agricultural Experiment Station.

[22] Personal communication from C. O. Stanberry, Washington Agricultural Experiment Station.

[23] Personal communication from Nels Benson, Washington Agricultural Experiment Station.

[24] Personal communication from G. O. Baker, Idaho Agricultural Experiment Station.

content of soils (*45*); however, conclusions were not drawn as to specific phosphorus needs of different soil types. In the fall of 1949 the Utah-Idaho Sugar Co. (*163*) collected soil samples from fields in the Chinook district. Results showed that 82 percent of the samples had 10 parts per million (p. p. m.) or less of CO_2-soluble PO_4. By the standards used, these data indicate that a large number of the fields were in need of phosphate fertilizer.

In Utah there was often as great a difference in phosphate response between crops in adjacent fields as between widely separated areas (*114*). Pittman and Thorne (*115, p. 17*) stated:

> The soils of that part of the State which drains into the Colorado River are almost all more or less benefited by the application of fertilizer containing available phosphorus when planted to those crops that are especially responsive to phosphorus.

During the fall of 1949 soil samples were taken from fields in three factory districts on which beets were to be grown in 1950 (*163*). Soil tests indicated that the CO_2-soluble PO_4 was much higher here than in Montana and South Dakota. Only about one-half of the Utah samples contained less than 10 p. p. m. of soluble PO_4.

In Colorado the variation in yield response has usually been as great within as between soil types (*14, 15, 39, 54, 100, 101, 102, 181*). The use of commercial fertilizers has altered the available phosphorus level of many fields.

Northern Plains States

Limited data in North Dakota (*154*) indicated some correlation between yield response and soil type. Soil type or series, however, apparently has not been used as a basis for phosphate recommendations (*63*). For example, the following quotation indicates the general conclusions:

> * * * the plant food most likely to be needed first is phosphate. * * * the only dependable way to find out if fertilizers will benefit yields is to try the fertilizer on that field. * * * Response from fertilizer application is also more likely in the older farming sections of the State and where rainfall during the season is most dependable.

Tests of soil samples (*163*) from sugar beet fields in Belle Fourche district in South Dakota indicated a widespread phosphorus deficiency. Sixty-eight percent of the samples collected contained 5 p. p. m. or less of CO_2-soluble PO_4, and 94 percent contained 15 p. p. m. or less.

In Nebraska, through field trials, chemical tests, and observations, some of the major soil series of the State have been classified as to their need for phosphate. Rhoades (*252*) gave these generalizations:

> Crop responses to applications of phosphate fertilizer are most likely to be obtained on the following groups of soils: Acid, medium to fine textured soils such as Carrington, Sharpsburg, and Marshall; acid sandy soils such as Thurman, Dickinson, O'Neill, and Cass; and calcareous soils such as Wann, Lamoure, Minatare, Crofton, Mitchell, and Bridgeport. Some response of crops to phosphate applications on other soils may be obtained where large crop yields have been removed for many years and little attention has been given to manure applications.

There is considerable variation in crop responses, however, within series and types caused by cropping sequence and fertilizer usage. A fair correlation has been found between the soluble phosphorus content

of the surface soil and the phosphate response of winter wheat in eastern Nebraska (*233*). This correlation was improved when nitrogen was applied in addition to the phosphate (*242*).

Data from Kansas indicated that leached soils of the eastern part, particularly the southeastern, were in need of phosphate (*112, 128, 130, 143–145, 200*).

COMPARISONS OF PHOSPHATE CARRIERS

Numerous experiments have been conducted to compare the relative effectiveness of various kinds of phosphate fertilizers (table 18). A few of the data were inconclusive, but nevertheless definite trends appear to exist. For the West in general, the phosphate carriers may be listed in approximately the order of their comparative effectiveness, thus:

$$\left.\begin{array}{l}\text{Ordinary superphosphate}\\ \text{Double superphosphate}\\ \text{Ammonium phosphate}\\ \text{Liquid phosphoric acid}\end{array}\right\} > \text{calcium metaphosphate} > \text{dicalcium phosphate} >$$

$$\text{tricalcium phosphate} \begin{array}{c}>\\ \text{or}\\ =\end{array} \left\{\begin{array}{l}\text{colloidal phosphate}\\ \\ \text{rock phosphate}\end{array}\right.$$

Generally the water-soluble forms appear to be the most effective sources of phosphate.

TABLE 18.—*Summary of experiments comparing various phosphorus carriers*

Area and State	Ref. No.	Phosphate materials compared [1]	Crop	Conclusions
Southwest:				
Arizona	*202*	Ordinary super, double super, phos. acid	Lettuce	No differences.
Do	*209*	Double super, phos. acid	Alfalfa, sorghum	No conclusions possible.
Do	*79*	Double super, tri-Ca, tri-Mg, di-Ca, di-Mg, Ca meta, Na meta, 11–48–0.	Neubauer [2]	Water solubles most effective.
Do	*256*	Double super, phos. acid	Alfalfa	No differences.
California	*217*	Double super, "Thermophos"	Potatoes, peas	Double super better.
Do	*110*	Ordinary super, double super	Sugar beets	No yield response.
Do	*266*	Double super, "Thermophos"	Potatoes	No differences.
Do	*179*	Ordinary super, double super	Alfalfa	Do.
Nevada	*148*	Double super, Ca meta, fused, sintered, and 11 organic phosphates.	Neubauer [2]	Do.
New Mexico	*51*	Ordinary super, double super, Ca meta, 11–48–0.	Alfalfa	11–48–0>supers>Ca meta.
Do	*151*	do	Cotton	No yield response.
Northwest:				
Oregon	*119*	Ordinary super, mono-Ca, rock	Major crops	Ordinary super best; rock no value.
Do	*121*	Ordinary super, double super, rock	do	Supers better.
Do	*129*	Ordinary super, mono-Ca	Alfalfa	Ordinary super better.
Do	*133*	Ordinary super, double super, rock	Major crops	Ordinary better than double super; rock no value.
Do	*152*	Ordinary super, double super, 11–48–0	Vetch, barley	11–48–0 most effective.
Washington	*9*	Supers, rock	Peas	Supers better than rock.
Do	(3)	Double super, Ca meta, di-Ca, K-Ca meta.	Alfalfa	No differences.
Idaho	(4)	Ordinary super, double super, phos. acid, K meta, K-Ca meta, super pellets.	do	Water-soluble forms best.
Do	(4)	Double super, phos. acid, Ca meta, K meta, tri-Ca, fused, rock.	Tomatoes (greenhouse).	Double super>K meta>phos. acid>Ca meta>fused>rock>tri-Ca.
Do	*68*	Western double super, TVA triple, Ca meta, fused, rock, calcined.	Major crops	Double supers best, rock poorest.

Do	*70*	Water soluble, citrate soluble	Romaine lettuce	Water soluble effective only.
Do	*102*	P32 tagged super, ammonium phosphate, Ca meta, tri-Ca.	Alfalfa	Super=ammonium phosphate>Ca meta>tri-Ca.
Mountain States:				
Montana	*17*	Double super, rock	Major crops	No response from rock.
Do	*45*	Double super, ammoniated	Potatoes	About equal.
Do	*42, 184, 185*	Ordinary super, double super, phos. acid, TVA triple, mono-Ca, di-Ca, Ca meta fused, rock.	Alfalfa, beets, small grains.	Double super>ordinary super>mono-Ca>di-Ca; Ca meta, fused, and rock very poor.
Wyoming	([5])	Double super, rock	Alfalfa, bromegrass	No response from rock.
Utah	*156, 157, 193*	Double super, phos. acid	Wheat, potatoes, beets.	Phos. acid equal but never superior to double super.
Do	([6])	Ordinary super, double super, Ca meta, K meta, fused, rock.	Alfalfa	Supers=K meta>Ca meta>fused or rock.
Do	*115*	Ordinary super, double super, Ca meta, fused, rock.	do	Supers and Ca meta equal; fused and rock inferior.
Do	*186*	Ordinary super, rock	Barley	Super better.
Colorado	*100–102*	Ordinary super, double super, phos. acid, 11–48–0, Ca meta, di-Ca.	Major crops	Phos. acid>supers=11–48–0>=Ca meta>di-Ca.
Northern Plains:				
North Dakota	*174*	Ordinary super, rock	Grains, potatoes	Super better.
Do	*275*	Double super, Ca meta, colloidal	Wheat	Super>Ca meta>colloidal.
South Dakota	*56*	Ordinary super, rock	Major crops	Super usually better.
Kansas	*28, 204*	Super, rock	do	Equal in extreme eastern part of State.

[1] Ordinary super=16 to 20 percent superphosphate; double super=40 to 50 percent superphosphate; phos. acid=liquid phosphoric acid; tri-Ca=tricalcium phosphate; tri-Mg=trimagnesium phosphate; di-Ca=dicalcium phosphate; di-Mg=dimagnesium phosphate; Ca meta=calcium metaphosphate; Na meta=sodium metaphosphate; mono-Ca=monocalcium phosphate; K-Ca meta=potassium calcium metaphosphate; TVA triple=TVA triple superphosphate; fused=fused tricalcium or rock phosphate; rock=rock phosphates; K meta=potassium metaphosphate; colloidal=colloidal rock phosphate.

[2] Greenhouse test using rye seedlings.

[3] Personal communication from C. O. Stanberry, Washington Agricultural Experiment Station.

[4] Personal communication from G. O. Baker, Idaho Agricultural Experiment Station.

[5] Personal communication from W. L. Quayle, Wyoming Agricultural Experiment Station.

[6] Personal communication from D. W. Pittman, Utah Agricultural Experiment Station.

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A few exceptions occur to this order. Sometimes ordinary superphosphate is more effective than double superphosphate because of the existence of a sulfur deficiency. Rock phosphate appears somewhat effective on the acid soils in western Oregon and Washington and in extreme eastern Kansas. It appears to be of no value on calcareous soils.

PLACEMENT OF PHOSPHATE

In Oregon, South Dakota, Nebraska, Nevada, New Mexico, and Wyoming placement variables apparently have not been investigated. In the other States a few trials have been conducted with each of the major crops. A summary of these experiments follows.

Alfalfa

Colorado studies (*102*) indicated that young alfalfa plants 6 to 8 inches high obtain more fertilizer phosphorus from superphosphate mixed into the soil by rototilling before planting than from a band placement made at the same time. Calcium metaphosphate and tricalcium phosphate supplied about the same amount of phosphorus from each placement. Placement had no effect at later samplings. In Utah (*193*) drilling was slightly more effective than broadcasting or liquid applications.

Small Grains

Studies in Colorado using radioactive fertilizers (*100, 102*) indicated that irrigated wheat and barley absorb more fertilizer phosphorus from rototilling the phosphate 4 inches deep than from rototilling it 2 inches deep. Also, rototiller placement appeared slightly more beneficial than band placement. With barley in North Dakota (*275*) no consistent differences resulted from placing 40 pounds of P_2O_5 in a band along the row, broadcasting and plowing it under, or broadcasting and disking it in after plowing. However, in three trials with spring wheat (*275*) drilling was more effective than broadcasting. With winter wheat in Kansas one experiment (*158*) showed that drilling the phosphate with the seed was superior to broadcasting, and another showed that drilling the fertilizer with the seed followed by a spring top dressing of nitrogen was the best practice.

Corn

At Barney, N. Dak., in 1948, (*275*) broadcasting and plowing under the phosphate appeared to give greater yield increases of corn than either broadcasting after plowing or banding along the row. One trial with sweet corn in Washington (*261*) showed that side-placement at seeding produced higher yields than broadcasting.

Sugar Beets

California greenhouse trials (*110*) showed that 150 pounds per acre of either single or double superphosphate placed in bands 1½ and 2½ inches to the side of the sugar beet seed reduced early emergence but

had no effect upon the final stand. Three hundred pounds of fertilizer at the 1½-inch placement seriously delayed emergence and reduced the final stand. Placement 1 inch below the seed had no deleterious effect. Nitrogen was always injurious. The effect on germination was believed closely associated with the moisture available for germination.

Colorado studies using radioactive fertilizer (*100–102*) showed that superphosphate supplied more phosphorus to the young plants when the fertilizer was mixed with the soil by rototilling than when it was placed in a band 4 inches to the side and 4 inches deep. Later sampling showed no benefit from either method.

Utah data (*62*) showed that broadcasting the phosphate resulted in higher yields than side dressing, and that applying 50 pounds per acre of double superphosphate with the seed plus a later side dressing was better than side dressing only. Liquid phosphoric acid (*193*) injected into the soil or applied in irrigation water was equally effective.

No difference in yields resulted from placement variables in Idaho (*62, 225*) or Montana (*262*).

Potatoes

Two band placements for potatoes were compared in Colorado, using 80 pounds of P_2O_5 per acre (*102*). In one the phosphate was banded 2 inches to each side of the seed piece at a depth of 2 inches. In the other it was placed in a band 2 inches to the side and 2 inches below on one side of the seed piece and 4 inches to the side and 4 inches below on the other side of the seed piece. Results showed a definite benefit upon fertilizer phosphorus uptake from the placement having the deep band.

Placement variables in Idaho had no influence upon yields (*160, 225*). Banding near the seed piece was more effective than surface drilling of the fertilizer in a nonirrigated field in Montana (*43*).

Truck Crops

On lettuce in Arizona, 11–48–0 banded 1½ inches on the furrow side of the seed and 3 inches below at the time of planting was inferior to a side dressing made 1 month later (*80*). In 2 experiments with lettuce in the Salt River Valley (*46*), banding 250 pounds of 0–44–0 was preferable to broadcasting. In another trial in the Yuma Valley (*46*), there was no yield difference between broadcasting and banding 0–18–0 and 11–48–0.

On onions in California results from several placement trials using nitrogen and phosphorus combinations were inconclusive (*217*). In one trial, the fertilizer applied under the plant row produced higher yields than when applied between the rows. In another, there were no yield differences between placements; however, the fertilizer placed under the plant row produced larger onions.

For canning peas in western Washington (*7, 8, 10*), placing the fertilizer ½ inch to the side of the seed was superior to placement either with the seed or 1½ to 2½ inches to the side.

Fruit Trees

Broadcast and furrow methods of phosphate application were compared in well-established peach, apricot, and prune orchards of California (*125*). There was no effect from either placement upon fruit yields, growth rate of the trees, date of ripening, or phosphorus content of the leaves.

RATES OF PHOSPHATE APPLICATION

Numerous trials have been conducted to determine the effect of different rates of superphosphate upon the yield of alfalfa, small grains, sugar beets, and potatoes. Only a few rate trials have been conducted with other crops. The trials were located on soils ranging from phosphorus-deficient to nondeficient soils. For the most part there has been a lack of chemical data on the soil and plants. As a result, it has been impossible to correlate the response obtained with soil-fertility levels, plant composition, and other factors.

Alfalfa

Striking benefits on alfalfa yields from increasing rates of P_2O_5 have been obtained on the Superstition sands near Yuma, Ariz., (*202*, *209*) and on the University Farm near Tucson (*82*). Some of the Yuma data are given in table 25. At Tucson maximum yields were produced from 400 pounds of 11–48–0 per acre.

Data from the Yuma Field Station at Bard, Calif., (*179*) showed increasing yield response up through the highest rate of 120 pounds of P_2O_5; however, a trial in Imperial County (*195*) showed no particular benefits beyond 36 pounds of P_2O_5 per acre.

It has been concluded in New Mexico (*52*) that 60 pounds of P_2O_5 applied at the beginning of the growing season gave the best returns. Either more frequent applications during the growing season or higher initial applications failed to increase yields on Gila clay beyond the 60-pound rate. Other trials (*176*) appeared to add support to the recommendation of a 60-pound annual application.

On Sagemoor fine sandy loam at Prosser, Wash., (*139*) annual applications of 0, 32, and 64 pounds of P_2O_5 resulted in average annual yields of 4.76, 5.75, and 6.42 tons of hay per acre, respectively. At Hermiston, Oreg., (*229*, *269*) rates higher than 80 pounds of P_2O_5 per acre had no significant effect upon yields.

Increasing increments of P_2O_5 at Aberdeen, Idaho, (*161*) [25] resulted in a fairly typical Mitscherlich yield curve. Some of the alfalfa-yield data from the 6-year rotation, 1939–41, are as follows:

P_2O_5 per acre, applied over 6 years:	*Total hay yield per acre*
	Tons
0	9.04
75	12.26
150	15.04
225	16.04

On more fertile soils (*226*) no major yield differences between rates were noted.

[25] Personal communication from G. O. Baker, Idaho Agricultural Experiment Station.

In Utah a considerable number of rate trials have been conducted (*115*, *268*). Most of the trials showed material increases in alfalfa yields up through 100 pounds of P_2O_5 per acre. Those conducted in 1949 are summarized in table 19.

TABLE 19.—*Response of alfalfa to various rates of superphosphate in Utah during 1949* (*268*)

Location	Yield per acre of alfalfa for the indicated acre rates of treble superphosphate		
	0 lb.	200 lb.	400 lb.
	Tons	*Tons*	*Tons*
Panguitch	0.97	2.05	2.68
Circleville	1.02	2.07	2.41
Kingston	1.86	2.25	2.29
Antimony	2.63	2.69	2.73
Petersboro	1.29	2.12	2.21
Duchesne County	7.55	8.26	8.70
Vernal	6.65	6.50	6.55
Lehi	1.71	3.19	3.03
Payson	3.79	5.44	5.19
Highland bench	6.04	6.06	6.16
Lehi	8.19	7.69	7.65
Benjamin	6.01	6.39	6.19
Mapleton	7.29	7.56	7.23
Levan	5.13	6.44	6.14

In Colorado (*102*) an application of 80 pounds of P_2O_5 per acre was no more effective than 40 pounds. The data from a series of rate trials on irrigated lands in western Nebraska (*78*) are summarized in table 20. On nonirrigated Sharpsburg silty clay loam in southeastern Nebraska (*59*), 139 pounds of P_2O_5 produced slightly higher yields than 45 pounds per acre (*205*).

TABLE 20.—*Alfalfa yields per acre on different irrigated soils in western Nebraska as influenced by rate of phosphate application* (*78*)

Soil type	Years tested	Check plot	Increase for the indicated acre rates of P_2O_5			
			32 lb.	45 lb.	68 lb.	90 lb.
		Tons	*Tons*	*Tons*	*Tons*	*Tons*
Tripp very fine sand	1	5.85	0.21	0.37	0.28	0.51
Mitchell silt loam	3	5.04	1.00	1.08	.97	1.12
Minatare very fine sandy loam	2	2.52	1.66	1.74	1.90	2.08
Minatare silt loam	3	2.43	1.20	1.52	1.92	2.30

Small Grains

In the Plains States on nonirrigated lands, 10 to 20 pounds of P_2O_5 per acre drilled with or near the seed of small grains produced near-maximum response. On irrigated lands elsewhere in the West, 40 pounds or more of P_2O_5 may give best returns.

Data from 10 trials with wheat, barley, and oats in California (*232*) are summarized in table 21. Since the different small grains behaved similarly, they were grouped together.

Table 21.—*Effect of various phosphate rates upon the yield per acre of small grain in California (232)*

P_2O_5 per acre [1] (pounds)	Average yield [2] on soils of moderate P deficiency	Average yield [3] on soils of acute P deficiency
	Pounds	*Pounds*
0	2, 040	1, 150
10	2, 392	1, 493
20	2, 421	1, 791
40	2, 441	2, 127

[1] In combination with 40 pounds of nitrogen per acre. At 8 locations the fertilizer was banded adjacent to the seed at planting, at 2 the fertilizer was broadcast as soon as the grain was up.
[2] Average of 4 locations.
[3] Average of 6 locations.

In Washington (*180*) 0, 40, 60, 120, and 160 pounds of P_2O_5 per acre produced oat yields of 69.7, 73.1, 75.8, 75.3, and 79.7 bushels per acre and wheat yields of 28.1, 31.9, 33.2, 32.0, and 29.6 bushels per acre, respectively. These were averages of 20 oat experiments and 5 wheat experiments from plots receiving a uniform application of nitrogen and potash.

In a 6-year rotation at Aberdeen, Idaho (*161*), 0, 75, 150, and 225 pounds of P_2O_5 produced wheat yields of 66.1, 69.6, 74.8, and 80.3 bushels per acre, respectively.

The yield of irrigated barley on Orem gravelly loam in Utah (*245*) was increased 13.6 percent from a broadcast application of 45 pounds of P_2O_5 per acre and 21.8 percent from 90 pounds of P_2O_5. A rate study [26] on dryland wheat showed no yield increases. Barley grown on an irrigated exposed subsoil in Colorado (*131*) yielded 8.5 bushels per acre without manure or phosphate, 18.3 bushels with manure, 23.2 bushels with manure plus 54 pounds of P_2O_5, and 25.2 bushels with manure plus 430 pounds of P_2O_5 per acre.

Twenty-three trials with wheat were conducted in North Dakota from 1947 through 1949 on nonirrigated lands in which 0, 11, and 22 pounds of P_2O_5 per acre were drilled with or near the seed (*211, 219, 273, 274, 275*). Average yields were 22.1, 25.9, and 26.4 bushels per acre, respectively. Forty-four pounds of P_2O_5 per acre were used in a few trials and produced only 0.25 bushel per acre more than the 22-pound rate.

[26] Personal communication from H. B. Peterson, Utah Agricultural Experiment Station.

Fifteen grain trials were conducted on nonirrigated lands in eastern Nebraska in 1938 and 1939, using 0, 40, and 80 pounds of 0–45–0 per acre (*272*). Rates of 20 to 30 pounds of P_2O_5 appeared sufficient; however, lack of nitrogen may have been a limiting factor.

A single trial with wheat in Cherokee County, Kans., (*158*) showed that 50 pounds of ordinary superphosphate per acre was as effective as higher rates. Another trial with wheat (*143*) indicated that 25 pounds of P_2O_5 was as effective as 50 pounds.

Sugar Beets

Rates ranging from 45 to 90 pounds of P_2O_5 per acre usually produced near-maximum yields of sugar beets, although higher rates occasionally appeared advisable.

The data from three rate trials conducted in California (*110*) are summarized in table 22. In one trial, yields were increased with increasing rates.

Table 22.—*Effect of increasing rates of P_2O_5 upon the sugar yield from beets grown on different soils in the Sacramento Valley, Calif.* (*110*)

Soil type	P_2O_5 per acre	Sugar yield per acre
	Pounds	*Pounds*
Ryde silty clay loam	0	4, 792
	60	7, 378
	120	7, 666
	180	7, 424
Staten peaty muck	0	7, 353
	450	6, 623
	2, 700	7, 247
Egbert muck	0	9, 242
	65	9, 072
	130	9, 067

Most of the rate trials conducted in Washington failed to reveal much benefit from phosphate (*64*, *180*, *237*). Out of seven trials conducted in 1945 (*162*) four responded, and the average yields from these were 26.0, 28.7, and 27.7 tons of roots for 0, 90, and 180 pounds of P_2O_5 per acre, respectively.

Average yields of nine trials in Idaho (*64*) were 13.46, 13.95, and 13.98 tons for 0, 68, and 136 pounds of P_2O_5 per acre. A rate trial at Aberdeen (*226*) showed no significant increases of sugar beet yields owing to phosphate. On unmanured land near Billings, Mont., (*117*) yields were 7.93, 12.45, 12.81, and 12.30 tons from 0, 45, 90, and 135 pounds of P_2O_5. On manured land the yields were 9.17, 10.81, 14.78, and 13.33 tons for the same treatments. At six locations on Utah-Idaho Sugar Co. fields (*64*, *164*) no benefits were obtained from phosphate at any of the rates applied.

Data from Utah (*62*) indicated that germination was injured where more than 50 pounds of 0–45–0 was applied with the seed. Results from 19 field trials (*64*) conducted in 4 counties are summarized in table 23.

TABLE 23.—*Response of sugar beets to various rates of superphosphate in Utah* (*64*)

Sugar district	Trials	Yield per acre of sugar beets for indicated rates of 0–45–0		
		0 lb.	150 lb.	300 lb.
	Number	*Tons*	*Tons*	*Tons*
Salt Lake and Utah	8	13. 98	14. 89	16. 53
Gunnison	5	15. 75	16. 46	16. 84
Box Elder	6	14. 15	15. 08	15. 64

In rate trials conducted at two locations in the Arkansas Valley in Colorado (*24*) average sugar yields were 3,094, 3,473, 3,580, and 3,799 pounds from 0, 86, 172, and 258 pounds of P_2O_5 per acre, respectively. In another trial at Fort Collins (*101*, *102*) beet yields were 17.9, 18.5, and 18.7 tons from 0, 40, and 80 pounds of P_2O_5 per acre. In this trial early vegetative response to phosphate was great. On June 10, 37.1, 55.8, and 64.5 grams of dry plant material were obtained from 96 feet of row for the three rates, respectively.

Average yields from eight trials in western South Dakota (*164*) were 10.83, 11.59, and 12.42 tons of beets from 0, 68, and 136 pounds of P_2O_5 per acre, respectively.

Data (table 24) from two low- and two medium-yielding fields in western Nebraska (*220*) showed that 90 pounds of P_2O_5 per acre produced maximum yields on the low-yielding fields, while 45 pounds were most effective on the medium-yielding fields. On three fields in the Gering area in western Nebraska (*220*) mean sugar yields were 4,364, 4,848, and 4,939 pounds of sugar per acre for 0, 100, and 400 pounds of P_2O_5, respectively.

TABLE 24.—*Response of sugar beets to various rates of P_2O_5 on low-yielding and medium-yielding fields in western Nebraska* (*220*)

P_2O_5 per acre (pounds)	Mean yield of beets per acre—	
	Low-yielding fields	Medium-yielding fields
	Tons	*Tons*
0	5. 0	11. 0
45	11. 0	14. 8
90	13. 4	13. 9
135	13. 0	14. 5

Potatoes

On McDonald Island in California (*266*) three rate studies were conducted using 0, 80, and 160 pounds of P_2O_5 per acre. Yields of potatoes were 373, 407, and 402 cwt., respectively, on Venice peaty muck; 456, 464, and 492 cwt. and 247, 275, and 303 cwt. in two experiments on Staten peaty muck. Uniform applications of nitrogen and potash were made on all the plots.

Thirty-four trials were conducted in Washington from 1933 through 1937 (*180*) in which rates of 0, 40, 80, 120, and 160 pounds of P_2O_5 per acre were applied in combination with nitrogen and potash. At 12 locations yield responses were observed, and at these either 80 or 120 pounds of P_2O_5 gave maximum or near-maximum responses.

In a rotation experiment at Aberdeen, Idaho, (*161*) applications of 0, 75, 150, and 225 pounds of P_2O_5 made during a 6-year period gave 2-year total yields of 475, 469, 529, and 586 bushels of potatoes per acre, respectively.

In one Montana trial (*45*) rates of 0, 56, and 112 pounds of P_2O_5 per acre produced yields of 143, 203, and 175 cwt., respectively, of potatoes. An unreported number of Montana trials were grouped according to fields low in organic matter and fields that had been in sod (*49*). Average potato yields from applications of 0, 45, and 90 pounds of P_2O_5 were 79, 86, and 92 cwt. per acre on the low organic-matter fields and 207, 229, and 212 cwt., respectively, on the sod fields.

A few rate trials on fields in Nebraska (*78*) indicated that 45 to 68 pounds of P_2O_5 per acre produced near-maximum yields of potatoes.

Other Crops

Too few rate trials have been conducted with other crops to justify detailed summarization. Rate trials on cotton have been reported in Arizona (*209*) and New Mexico (*106*, *150*), on lettuce in Arizona (*27*, *208*), on truck crops in California (*217*, *265*) and Nevada (*48*), on hops in Oregon (*224*), on canning peas in Washington (*9*, *180*), and on irrigated pastures in Utah (*268*).

RESIDUAL INFLUENCE OF PHOSPHATE UPON CROP YIELDS

Phosphate fertilizers may influence crop yields for a number of years following their application to western soils. McGeorge (*79, p. 328*) stated:

> Soluble phosphate fertilizers are fixed in a form which is surprisingly available as shown by the residual response obtained in pots and in the fields.

Residual response has been noted for as long as 7 years following application, the degree of response depending upon the initial rate of application.

A number of trials have been conducted in which marked phosphorus carryover has been noted the second year. These include trials with alfalfa on the University Experimental Farm, Mesa, Ariz. (*209*); alfalfa at Bard, Calif. (*179*); sugar beets in Colorado (*153*); alfalfa

(*17*) and potatoes (*50*) in Montana; alfalfa (*48*) and barley (*259*) in Nevada; alfalfa in New Mexico (*51*); and barley in North Dakota (*275*).

A few experiments have been conducted in which the residual phosphate response has been measured for several years. On the Yuma Mesa in Arizona, a residual experiment involving several rates of superphosphate was started in 1945 on an extremely phosphorus-deficient Superstition sand (*202*). The fertilizer was applied and Sudan grass sown in the fall of 1945 as a nurse crop; data on alfalfa yields were obtained for 3 years (table 25). Pronounced residual responses still existed after 3 years.

TABLE 25.—*Effect of initial application of superphosphate upon the yield per acre of alfalfa over a 3-year period, Yuma Mesa, Ariz.* (*209*)

P_2O_5 per acre applied in 1945 (pounds)	Hay yield		
	1946	1947	1948
	Tons	*Tons*	*Tons*
100	1. 69	3. 36	3. 16
200	2. 99	5. 57	5. 19
400	5. 14	8. 23	6. 53

In Colorado an application of 5,000 pounds of 0–45–0 made in 1935, increased sugar beet yields in 1942 and 1944 (*153*).

A long-term residual phosphate experiment was started in 1937 at Aberdeen, Idaho.[27] Data from one phase of this experiment are reported in table 26. Residual response was observed for 7 years following the last application of phosphate.

TABLE 26.—*The residual influence of various rates of superphosphate upon the yield per acre of crops at Aberdeen, Idaho* [1]

P_2O_5 per acre (pounds) [2]	Alfalfa							Potatoes		Wheat
	1937	1938	1942	1943	1944	1948	1949	1945	1946	1947
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Bu.*	*Bu.*	*Bu.*
0	4. 29	4. 23	3. 75	3. 10	4. 47	2. 40	2. 13	171	190	72. 6
75	5. 80	4. 82	4. 75	4. 53	4. 98	2. 55	2. 07	187	200	72. 1
125	5. 70	5. 06	4. 72	5. 12	5. 48	3. 05	2. 39	194	199	71. 6
200	5. 49	4. 97	6. 28	6. 17	6. 28	4. 10	2. 54	193	215	71. 8
300	5. 75	5. 94	5. 64	5. 65	6. 10	4. 17	3. 07	198	197	76. 8

[1] Personal communication from G. O. Baker, Idaho Agricultural Experiment Station.
[2] Applied in 1937 and 1942.

[27] Personal communication from G. O. Baker, Idaho Agricultural Experiment Station.

Two residual experiments with alfalfa were conducted in the North Platte Valley of western Nebraska (*78*). Both experiments were on phosphorus-deficient soils, and the superphosphate was drilled into established stands of alfalfa in the spring of the first year. Residual response was still clearly visible the third year, particularly where the higher rates of P_2O_5 were used (table 27).

TABLE 27.—*Residual effect of several phosphate rates upon the yield per acre of alfalfa grown on 2 soils in western Nebraska* (*78*)

Soil and pounds per acre of P_2O_5	Yield of alfalfa		
	1st year	2d year	3d year
	Tons	*Tons*	*Tons*
Mitchell silt loam:			
0	4. 73	5. 26	5. 14
31.5	5. 57	5. 98	5. 46
45.0	5. 67	6. 18	5. 79
67.5	5. 45	6. 33	5. 61
90.0	5. 64	6. 59	5. 88
Minatare silt loam:			
0	2. 31	2. 52	2. 46
31.5	3. 59	2. 87	2. 86
45.0	3. 93	3. 37	2. 83
67.5	4. 37	3. 56	3. 42
90.0	4. 41	3. 80	4. 23

In Utah (*113*) 430 pounds of P_2O_5 per acre increased the yield and phosphorus content of alfalfa for 5 years. In another trial (*192*) 125 pounds of "phosphorus fertilizer" applied in 1929 increased the yields of alfalfa as much in 1930, 1931, 1932, and 1933 as it did during the year of application, or more in some cases.

An alfalfa experiment was started on Millville loam at Logan, Utah, (*115*) in the spring of 1938 in which the phosphate was broadcast and harrowed into the soil at the time of seeding. The alfalfa hay yields over a 3-year period are given in table 28.

TABLE 28.—*Residual effect of superphosphate rates upon the yield per acre of alfalfa at Logan, Utah* (*115*)

P_2O_5 per acre (pounds)	Yield of alfalfa		
	1939	1940	1941
	Tons	*Tons*	*Tons*
0	2. 76	2. 17	2. 31
50	4. 45	2. 97	2. 42
100	5. 45	3. 59	2. 64

EFFECT OF PHOSPHATE FERTILIZERS UPON THE COMPOSITION AND QUALITY OF CROPS

Alfalfa

Phosphate fertilizer has consistently increased the phosphorus content of alfalfa hay. There is also some evidence that phosphate fertilizer increases the protein content of the hay.

The relation between the rate of phosphate application and the phosphorus content of alfalfa is strikingly shown by data (table 29) from an experiment in the Santa Cruz Valley, Ariz. (*82*). Ammonium phosphate, 11–48–0, was drilled into an established alfalfa stand immediately after the first cutting of hay was removed.

Table 29.—*Effect of various rates of 11–48–0 upon the yield per acre and phosphorus content of alfalfa hay in the Santa Cruz Valley, Ariz.* (*82*)

Pounds 11–48–0 per acre	5 cuttings hay (1934)		6 cuttings hay (1935)	
	Yield	P content	Yield	P content
	Pounds	*Percent*	*Pounds*	*Percent*
0	3, 374	0. 163	3, 395	0. 201
100	4, 972	. 197	4, 045	. 196
200	5, 174	. 216	4, 815	. 196
400	5, 534	. 233	5, 755	. 218
600	5, 421	. 239	5, 490	. 222

During 1949, 719 alfalfa samples were taken throughout California at harvesttime.[28] The phosphorus content of the alfalfa was determined, using 2 percent citric acid as the solvent. Of the samples 11.4 percent were very low, containing less than 500 p. p. m. soluble phosphorus, and 47.8 percent were low, containing less than 1,000 p. p. m.

In the Moapa Valley, Nev., (*48*) 225 pounds of P_2O_5 per acre increased the yield of alfalfa hay by 41 percent and its phosphorus content from 0.149 percent on the checks to 0.192 percent on the fertilized plots. In another trial (*48*) in the same valley, the hay yield was increased by 45 percent and the phosphorus content by 30 percent.

In New Mexico (*52*) 60 pounds of P_2O_5 per acre increased the annual yields from 5 tons on the check plots to 7.7 tons on the fertilized, while the phosphorus content was increased from 0.162 percent to 0.210 percent.

At Hermiston, Oreg., (*269*) 0, 80, and 160 pounds of P_2O_5 per acre produced hay yields of 6.02, 6.68, and 7.12 tons and phosphorus contents of 0.228, 0.248, and 0.256 percent, respectively.

The yield and composition of alfalfa hay were reported for 15 locations in Washington where 0 and 96 pounds of P_2O_5 per acre had been applied annually from 1 to 3 years (*173*). The means for the

[28] Personal communication from W. E. Martin, California Agricultural Extension Service.

nonphosphated and phosphated hay were 1.94 and 2.49 tons of hay and 0.260 and 0.268 percent phosphorus, respectively. The phosphorus content of the nonphosphated plots ranged from 0.189 to 0.344 percent; in several instances phosphate failed to increase the phosphorus composition of the hay. On Sagemoor fine sandy loam at Prosser (*139*) the phosphorus composition of check plots ranged from 0.109 to 0.149 percent. Phosphate fertilizer increased the phosphorus percentage materially. In several studies (*139*, *172*, *173*) phosphate apparently had no influence upon the content of ash, nitrogen, potassium, and calcium.

On a phosphorus-deficient soil at Aberdeen, Idaho, (*58*, *59*, *96*)[29] increasing the rate of P_2O_5 increased both the phosphorus and protein content of the alfalfa. Some of the data are shown in table 30. Phosphorus contents of alfalfa grown on the untreated check plots at Aberdeen, Moscow, and Sandpoint were 0.138, 0.285, and 0.189 percent, respectively. Marked yield responses were obtained at Aberdeen, none at Moscow, and a slight response at Sandpoint.

TABLE 30.—*Yield per acre and protein and phosphorus content of alfalfa as influenced by rate of phosphate at Aberdeen, Idaho* (*59*)

Pounds P_2O_5 per acre	Yield of alfalfa	Proteins	Phosphorus
	Tons	*Percent*	*Percent*
0	4. 04	16. 06	0. 138
75	4. 93	16. 49	. 161
150	5. 75	16. 99	. 175
225	6. 17	17. 40	. 180

The average of first cuttings at 27 locations in Montana during 1934 (*43*) showed the following relationships:

	Phosphorus content (percent)	*Yield per acre (tons)*
Check plots	0. 174	1. 46
Phosphated plots	. 198	1. 64

In order to show the variations encountered in yield and phosphorus composition, data (table 31) are given for trials conducted in Montana during 1938 (*184*).

In Utah during 1938 (*210*) 83 samples of alfalfa, representing first, second, and third crops of hay, were collected from farms throughout the State and analyzed for phosphorus, calcium, nitrogen, and ash. The mean phosphorus percentage was 0.246, the minimum 0.144, and the maximum 0.351 (fig. 8).

One experiment in Carbon County, Utah (*192*), over a 5-year period, showed an average yield response of 61 percent from an initial application of 56 pounds of P_2O_5 per acre. The fertilizer not only increased the phosphorus percentage but also the calcium, magnesium, and crude protein percentages (table 32).

[29] Personal communication from G. O. Baker, Idaho Agricultural Experiment Station.

TABLE 31.—*Yield per acre and phosphorus content of first cutting of alfalfa from phosphated and check plots at 15 locations in Montana during 1938 (184)*

Farm	Yield		Phosphorus	
	Check	Phosphated plots [1]	Check	Phosphated plots [1]
	Tons	*Tons*	*Percent*	*Percent*
Cotter	0. 54	1. 45	0. 146	0. 171
Noble	1. 56	1. 77	. 228	. 227
Wieferich	1. 42	1. 42	. 186	. 185
Kickbush	1. 32	1. 40	. 131	. 153
Gaarder	. 78	1. 11	. 171	. 193
Hoover	1. 06	1. 15	. 211	. 227
Hendrickson	. 93	1. 03	. 186	. 182
Salmonson	1. 38	1. 52	. 206	. 214
Jenkins	. 81	1. 03	. 111	. 166
Eastwood	1. 36	1. 58	. 200	. 196
Larsen	1. 28	1. 83	. 179	. 221
Loon	. 45	. 94	. 129	. 206
Lenz	. 57	. 79	. 131	. 190
Johnson	1. 58	1. 66	. 215	. 197
Tebay	1. 83	1. 98	. 175	. 262
Average	1. 12	1. 38	. 174	. 199

[1] 56 pounds of P_2O_5 per acre.

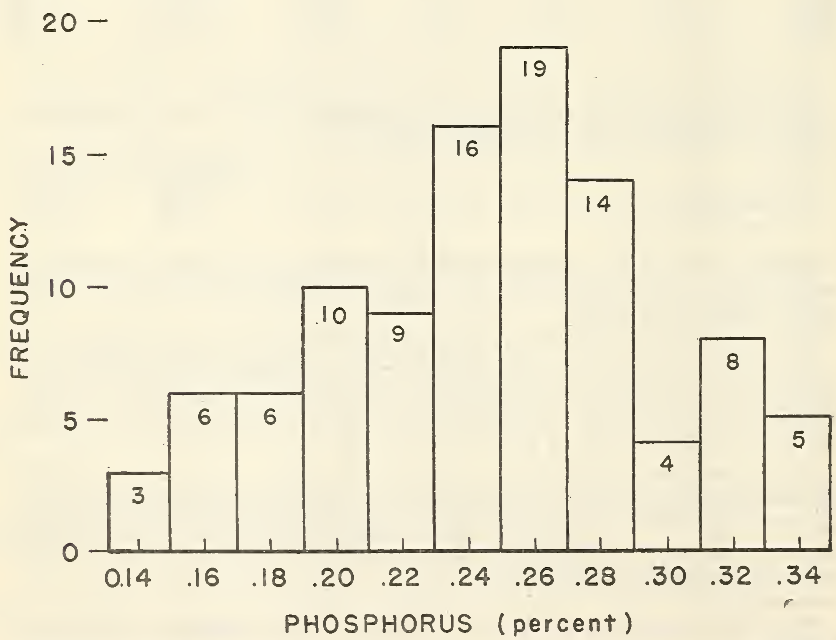

FIGURE 8.—Distribution of phosphorus percentages for 83 samples of alfalfa collected from farmers' fields in Utah during 1938 (*210*).

TABLE 32.—*Average percentages of phosphorus, calcium, magnesium, and crude protein on phosphated and nonphosphated alfalfa growing on a phosphorus-deficient field in Utah* (*192*)

Cutting	Phosphated fields				Nonphosphated fields			
	P	Ca	Mg	Protein	P	Ca	Mg	Protein
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	0. 299	3. 26	0. 66	15. 00	0. 203	2. 26	0. 63	13. 84
2	. 342	2. 99	. 64	16. 09	. 198	2. 32	. 31	13. 75
3	. 271	3. 09	. 66	15. 45	. 173	2. 47	. 36	13. 10
Mean	. 304	3. 11	. 65	15. 51	. 191	2. 35	. 43	13. 56

In an experiment where phosphate more than doubled the yields of the alfalfa at Logan in 1939 (*115*), the phosphorus percentage in alfalfa was 0.18 on the check plots and 0.20 on the phosphated.

PASTURES, GRASSES, AND OTHER HAYS

Superphosphate materially increased the phosphorus content of a mixed Ladino and grass pasture in Oregon (*122*). The phosphorus percentage of the untreated herbage was 0.279, while that of the phosphated herbage was 0.360. The addition of phosphate also increased the calcium, nitrogen, and protein content of the pasture. In another experiment with a similar pasture mixture (*33*), phosphate had no influence upon composition.

With pasture herbage in Washington (*172*) phosphate increased the phosphorus content markedly and nitrogen content slightly. With mixed grass hays the same trend existed, but to a lesser extent. The composition of oat and wheat hay was not affected materially.

On dairy pastures in Utah (*115*) the phosphorus and nitrogen contents of the forage were higher on the phosphated plots. Also, the proportion of clover in the forage was increased on the phosphated plots.

SMALL GRAINS

Phosphate fertilizers frequently increased the phosphorus content of the grain and straw. The protein content of wheat was often decreased; however, owing to increased yields, the total protein production per acre usually was increased. Test weight was either increased slightly or not affected.

Data from eight small-grain trials in California (*232*) showed slight but inconsistent increases in the phosphorus and protein contents of the grain. Phosphate applications made at Aberdeen, Idaho,[30] on a phosphorus-deficient soil increased the phosphorus content of wheat grain from about 0.25 percent on the check plots to 0.34 percent on the phosphated. There was no apparent increase in the protein content.

[30] Personal communication from G. O. Baker, Idaho Agricultural Experiment Station.

In Kansas the effects of phosphate fertilizers have been determined upon the test weight, protein content, maturity, and baking quality of wheat. In one series of rotation experiments (*159*) it was found that phosphate decreased the protein content, often increased the test weight, and failed to improve the baking quality of wheat. In another series of trials conducted from 1931 through 1938 (*130*), phosphate, while increasing the grain and straw yields, also increased the test weight by 0.8 to 1.6 pounds per bushel. Although the phosphate decreased the protein content of the grain, this was more than offset on an acre basis by the increase in yield. The percentage of yellowberry grain was not affected except in 1935, when it was increased. In these trials the addition of phosphate hastened maturity on all varieties one-half day to 3 days. In trials conducted in 1946 (*143*) and in 1947 and 1948 (*145*), phosphate applications had no influence upon either protein content or test weight. In trials in 1949 (*200*), however, phosphate again lowered the protein content of the grain.

In Montana (*43*, *45*) phosphate increased the phosphorus content of the grain and straw slightly. There was no appreciable effect from phosphate upon the protein content of wheat grain in Nebraska (*215*) or upon either protein content or test weight of the grain in North Dakota (*154*, *212*, *238*).

Sugar Beets

Phosphate fertilizer apparently had no consistent influence upon the sucrose percentage of sugar beet roots. In an attempt to arrive at a semiquantitative evaluation, data from 3 States were segregated according to the number of locations where the sucrose percentage was either increased or decreased from applications of phosphate. The sugar percentage was increased in 7 trials in California by an average of 0.41 percent and decreased in 12 trials by an average of 0.79 percent. It was increased in 53 trials in Colorado by an average of 0.80 percent and decreased in 33 trials by 0.46 percent. It was increased in 37 trials in Nebraska by an average of 0.34 percent and decreased in 16 by an average of 0.23 percent.

A trial conducted on Staten peaty muck in California (*110*), to determine the effect of very high rates of fertilizers upon yield and sugar content of beets, showed that the high rates of superphosphates did not materially affect either yields or sucrose percentages (table 33).

A pot experiment, using a phosphorus-deficient California soil, was conducted in which phosphate rates varied from 0 to 3,200 pounds per acre (*169*). The data showed that the weight of green tops and roots of beets increased rapidly for the first few rates of phosphate additions and then more slowly at the higher rates (table 34). The soluble phosphorus contents of the petioles and blades increased very slowly for the first few phosphate additions and then very rapidly, with the blades attaining a higher soluble phosphorus concentration than the petioles at the higher rates. The soluble potassium, however, decreased as the phosphate was increased. The nitrate concentrations in the petioles decreased only at the high phosphate rates. The sugar percentages of the beet failed to change significantly, even though large changes took place in the beet yields and in the phosphorus and potassium concentrations of the leaves.

TABLE 33.—*Effect of luxury amounts of fertilizers upon the yield and sucrose content of sugar beets grown on Staten peaty muck in California* (*110*)

Fertilizer used	Rate per acre			Yield per acre		
	N	P_2O_5	K_2O	Gross sugar	Beets	Sucrose
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Tons* [1]	*Percent*
Untreated	0	0	0	7, 353	24. 7	14. 9
Treble superphosphate	0	450	0	6, 623	25. 5	13. 0
Do	0	2, 700	0	7, 247	25. 7	14. 1
Superphosphate	0	2, 700	0	6, 384	26. 8	11. 9
Mixed fertilizer	0	1, 200	1, 500	6, 721	26. 1	12. 9
Complete fertilizer	0	800	800	7, 706	31. 1	12. 4

[1] Least significant difference (L. S. D.) at 5-percent level=4.04 tons.

TABLE 34.—*Effect of increasing amounts of phosphate upon the growth and composition of sugar beets grown in pots of Aiken clay in California* (*169*)

P_2O_5 per acre (pounds)	Green weight		Sugar	Soluble P in—		Soluble K in—		NO_3—N in petioles
	Tops	Roots		Petioles	Blades	Petioles	Blades	
	Gm.	*Gm.*	*Percent*	*P. p. m.*	*P. p. m.*	*Percent*	*Percent*	*P. p. m.*
50	256	202	13. 1	201	289	3. 42	3. 17	3, 590
100	454	346	13. 0	210	378	2. 35	3. 22	3, 890
200	765	493	13. 6	355	680	1. 31	2. 43	4, 680
400	892	653	13. 3	786	1, 070	1. 25	2. 19	3, 160
800	953	607	14. 0	1, 768	1, 700	1. 09	1. 98	1, 750
1,600	1, 026	637	14. 0	2, 953	3, 956	1. 08	1. 98	1, 940
3,200	1, 011	686	13. 5	3, 214	5, 078	1. 15	1. 85	2, 120
L. S. D. at 5-percent level	145	115	-------	275	790	. 35	. 46	1, 280

Data from Huntley, Mont., (*1, 2, 3, 91*) showed that phosphate applied to a phosphorus-deficient soil reduced the incidence of seedling diseases (table 35). As the nitrogen and phosphorus concentrations in the beet plants decreased, the amount of seedling diseases increased (*91*). It was concluded that a soil deficient in available phosphorus or nitrogen, or both, or an unbalanced ratio of these fertilizers gives beets a tendency to seedling diseases (*2*).

TABLE 35.—*Effect of fertilizers upon the incidence of sugar beet seedling diseases at Huntley, Mont.; average, 1941–44* (*1*)

Fertilizer applied [1]	Beet yield	Healthy seedlings
	Tons per acre	*Percent*
Check	4. 39	27. 8
P	9. 54	59. 3
N	7. 03	44. 7
N–P	10. 81	66. 5
N–P, plus manure	14. 91	69. 9

[1] P=phosphate at rate of 80.5 lb. of P_2O_5 per acre; N=nitrogen at rate of 36.5 lb. of N per acre; manure, applied at rate of 16 tons per acre.

POTATOES

Phosphate failed to influence the grade and quality of potatoes in Colorado (*84*, *227*), Idaho (*69*, *160*, *225*, *226*), Washington (*228*), and Oregon (*13*).

COTTON

A 12-year study with cotton in New Mexico (*53*) showed that annual applications of 135 pounds of treble superphosphate or 150 pounds of ammonium sulfate per acre did not materially affect the yield, staple length, lint percentage, boll size, or maturity of cotton. In Arizona (*209*), however, phosphate was found to increase the boll size and staple length, but not enough to justify the use of fertilizer.

TRUCK CROPS

With lettuce in Arizona (*27*, *46*, *83*) the size and compactness of the head was increased and the maturity was materially hastened from phosphate fertilization. With peas in Montana (*44*) phosphate generally increased the percentage of Grade A and Grade B peas and reduced the percentage of Grade C and culls. Tomatoes grown on phosphated land in Utah (*116*) had the highest total yields as well as the highest percentage of No. 1 fruit. Studies in Moapa Valley, Nev., (*244*, *259*) showed that phosphate favorably benefited tomato plants for shipping as transplants. The quality of hops was not altered by applications of phosphate in an experimental plot near Corvallis, Oreg. (*224*). Phosphate applications did not influence the phosphorus composition of spinach grown in the greenhouse on three western Washington soils (*165*).

TREE CROPS

With grapefruit in Arizona (*34*), phosphate applied to the soil had no effect on yields, fruiting behavior of the tree, or the amount of phosphorus in the leaves and fruit.

Phosphate applied on a phosphorus-deficient Aiken soil in California (*71*) failed to increase the yield of peaches, affect the time of bloom,

the time of ripening of the fruit, or the amount of shoot growth. Early in the season the fertilized trees appeared thriftier and had larger and darker foliage than the untreated trees. In August, however, the phosphated trees appeared yellowish green. The phosphated trees retained their leaves longer and did not develop purple-tinted leaves late in the season as did the untreated trees. In another trial with peaches on Aiken soils (*73*), 10 pounds of treble superphosphate were placed in the hole at planting time. This resulted in increased growth and in a marked increase in the phosphorus content of the leaves during the first season, but there were only slight increases in the second and third seasons.

Data from 130 orchards in California (*74*) showed that the phosphorus percentage of the leaves decreased rapidly during spring and early summer and then continued at a minimum level until fall. The phosphorus content of leaves taken in midsummer also varied markedly with nitrogen fertilization and irrigation. The magnitude of the difference produced by these two factors in a single orchard corresponded to the difference found between the high and low analyses in the 130 orchards. For all orchards, the percentage of phosphorus averaged 0.185 and the range was from 0.14 to 0.27. Poorest growth was frequently associated with the highest phosphorus content of soils and best growth with lowest phosphorus content. In another California study (*75*) applications of phosphate to the soil had no effect upon the yield and growth of established fruit trees or upon the quality of the fruits, even though it markedly increased the yield of 18 annual crops in the same orchards.

A fertilizer experiment with citrus in California was conducted, using 55-gallon pots filled with phosphorus-deficient Hanford fine sandy loam (*19*). Acute phosphorus deficiency developed in trees receiving nitrogen and potash but no phosphate. The deficiency was characterized by greatly reduced growth rate, small leaves, lack of branching, weak and slow terminal growth, and bronze or dull-green color of older leaves. The phosphorus content of the plant parts was increased considerably with the application of phosphate. Other studies with sand cultures (*20*) showed definitely that quality of citrus fruits could be affected significantly if the phosphorus levels of the sand were varied widely enough. Increasing the phosphorus apparently decreased the acidity of the fruit and resulted in smoother and thinner rinds and a higher juice percentage. The fruit appeared more solid, though not quite so highly colored. Chapman, Brown, and Rayner (*21*) have summarized the symptoms, cause, and control of phosphorus deficiency of citrus.

On apples (*92, 104, 105*) and pears (*103*) in Washington, applications of phosphate to the soil had no effect on quality and growth. Phosphate applied to soil on Lambert cherries in Utah (*157*) failed to influence the yield, grade of fruit, or growth of branches. Peaches in Utah (*149*) also failed to benefit from phosphate fertilizer. Applications of phosphate have shown no beneficial effect upon the yield or quality of apples and prunes in Idaho (*168*).

OCCURRENCE OF PHOSPHORUS MALNUTRITION IN ANIMALS

A few instances have been reported in which low phosphorus contents of forages have caused phosphorus malnutrition in animals. The writers have made no attempt to make a thorough review of the literature on this subject.

Parturient hemoglobinemia of dairy cows, caused by a phosphorus-deficient diet, has been detected in various locations in Utah (*85–87*). The disease apparently is becoming less prevalent (*87*), possibly as a result of more widespread use of bonemeal supplement and phosphate fertilizers.

Several instances of malnutrition have been reported in Oregon.[31] Symptoms in steers have included bone chewing, low blood phosphorus, and broken bones. Animals have responded to phosphate supplements.

Montana reported the existence of phosphorus-deficient sections where supplemental phosphorus is needed in the diet of livestock (*178*). Low blood phosphorus in cattle and very low phosphorus contents in the forages eaten have been reported on range lands in New Mexico (*65, 177, 270, 271*).

Beeson (*11*), in reporting known areas of mineral-deficiency diseases in animals, indicates observations of phosphorus malnutrition in parts of California, Nevada, New Mexico, Oregon, Idaho, Montana, and North Dakota.

AN EVALUATION

As indicated in this review, phosphate fertilizers have received considerable attention by western agronomists and soil scientists during the period 1910–50. In many of the field trials, the objective was to demonstrate the need for phosphate. Some field experiments have been designed to study the more basic principles of phosphate use. In recent years an increasing emphasis has been placed upon the more informative studies.

The widespread need and value of phosphates has been demonstrated. However, data on consumption of phosphates by crops appear to indicate that the farm practice is not being tied closely enough to research findings. For example, research data indicate that small grains usually respond to phosphate; yet farmers actually apply less than 1 pound of P_2O_5 per harvested acre. On the other hand, cotton and tree crops show only slight or no response to phosphates, but farmers are applying between 8 and 10 pounds of P_2O_5 per harvested acre. Potatoes, a questionable responder, receives about 32 pounds per acre.

Phosphate needs of most of the major crops have been more or less thoroughly investigated, although information is meager or lacking on some. For example, pastures and mountain meadows have received relatively little attention, and sorghums, small fruits, and vine crops have not been studied.

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[31] Personal communication from J. R. Haag, Oregon Agricultural Experiment Station.

Usually, the major emphasis has been placed upon individual crops rather than upon the soil. Apparently very little is known about fertilizing a given soil so that the phosphorus requirements of all crops grown on this soil are adequately met.

The literature review indicates that few investigators have related observed yield responses to soil types and soil properties. It is almost impossible, therefore, to project the information gained from experimentation into farm practice or to relate one experiment to another. A general lack of supporting laboratory data makes it difficult to explain adequately the field observations.

The comparative value of various phosphate carriers appears to have been rather thoroughly determined. It would seem that little need still exists for additional short-time comparisons of ordinary superphosphate, double superphosphate, liquid phosphoric acid, ammonium phosphate, calcium metaphosphate, dicalcium phosphate, fused or tricalcium phosphate, and rock phosphate on calcareous soils. A need does exist, however, for evaluating new materials such as nitrophosphates, for determining the effect of different degrees of ammoniation upon the availability of phosphorus, and for determining long-time residual effects of some of the water-insoluble carriers.

Placement studies with phosphates have been rather limited, particularly in respect to the use of starter phosphate for row crops in the more northern States. Greater emphasis upon placement studies would appear justified.

Although a considerable number of phosphate-rate studies have been conducted, very few are adequate for economic evaluation and interpretation. The characteristics needed to permit economic analysis, which are also those for a good rate experiment, involve a series of rates covering a wide range beyond which little or no response is obtained and within which there are no wide intervals between the different rates. Such an experimental plan is to be preferred to one in which rates are few in number and limited to only a portion of the response curve. Residual responses should be evaluated and the conditions under which the experiment was performed should be known.

Data from a few locations indicate that the residual carryover of phosphate in western soils has persisted for several years, especially where the initial application was large. Additional information, however, is desirable in order to evaluate more fully the residual behavior of various rates of phosphate.

The question of major concern to the individual farmer—Do my fields need phosphate and, if so, how much?—still remains an individual problem. It will be necessary for field trials to be correlated with good soil tests, plant composition, soil types and soil properties, past farming practices, and systems of farming before this question can be answered. The development of a test or tests that will permit reliable prediction of the phosphorus status of different soils in the West is believed essential.

Since about 1948 the tempo of research with phosphates in the West has increased rapidly. Much of the needed information is being supplied through these investigations.

SUMMARY

Phosphate fertilizer field investigations conducted in 15 Western States by State and Federal agencies and by commercial companies through 1949 are reviewed and summarized. Out of masses of heterogeneous and frequently contradictory data certain generalizations can be drawn.

Crops throughout the West show extreme variability in their response to phosphate fertilizers. For a given crop, responses may differ from field to field and from year to year. Some crops appear more responsive than others. Alfalfa appears to be one of the most responsive; for example, of 270 locations, 30.6 percent gave an annual response of 1 ton of hay per acre or more and 65.1 percent, of 0.4 ton or more. Small grains, particularly wheat, show fairly consistent responses on phosphorus-deficient soils except where other factors are limiting. In 470 trials with wheat, 30.9 percent gave increases of 5 bushels per acre or more and 73.4 percent, of 1 bushel or more. Corn seldom responds to phosphate, although occasionally material increases were obtained. Sugar beets frequently respond. In 173 sugar beet trials, 11 percent showed increases of 5 tons per acre or more and 76.4 percent, of 1 ton or more. Cotton responds only slightly. The response by truck crops is most valuable; large increases are often obtained on low-fertility soils and in fast-growing crops during cool seasons. Vegetative growth of tree crops may benefit from phosphate, but fruit yields apparently are not increased.

Phosphate response by crops generally has not been related to specific soils and soil properties. However, the Superstition sands of Arizona, the Aiken series of California, the "red hill" soils of Oregon, and the acid soils of Carrington, Thurman, Dickinson, O'Neill, Cass, and Sharpsburg series and the calcareous soils of the Wann, Lamoure, Minatare, Crofton, Mitchell, and Bridgeport series of Nebraska are frequently found deficient. Some soils in the Palouse section of Idaho and Washington and the newly broken soils of the Columbia Basin appear well supplied with available phosphorus. As a rule, however, response variations are as great within soil types as between.

Numerous comparisons have been made with different phosphate carriers. For the nonacid soils of the West, the relative effectiveness of the different carriers are approximately in the following order:

$$\left.\begin{array}{l}\text{Ordinary superphosphate}\\ \text{Double superphosphate}\\ \text{Ammonium phosphate}\\ \text{Liquid phosphoric acid}\end{array}\right\} > \text{calcium metaphosphate} >$$

$$\text{dicalcium phosphate} > \text{tricalcium or fused phosphate or} \begin{array}{l} > \\ = \end{array}\left\{\begin{array}{l}\text{colloidal phosphate}\\ \text{rock phosphate}\end{array}\right.$$

On sulfur-deficient soils, ordinary superphosphate is the most effective.

A few placement trials have been conducted. From these it appears that the most effective placements of phosphate are drilling with or near the seed for small grains, broadcasting or rototilling in bands for sugar beets, and banding about ½ inch to the side of the seed for peas. On other crops, too few data are available to be conclusive.

Too few rate trials have been conducted on most crops and soils to justify conclusions. However, alfalfa hay yields generally increase as the rates of application are increased, up through 100 pounds of P_2O_5 per acre. Small grains on nonirrigated lands in the Plains States usually show near-maximum responses from 10 to 20 pounds of P_2O_5 per acre drilled with or near the seed, while on irrigated lands elsewhere best response usually is from 40 pounds of P_2O_5 or more. Sugar beets, on responding fields, usually produce near-maximum yields from 45 to 90 pounds of P_2O_5 per acre.

Soluble phosphate fertilizers remain surprisingly available in western soils as indicated by residual response. In Idaho, for example, crop responses were observed for 7 years following the application of phosphate fertilizer. Most data indicate that the residual carryover is directly related to the amount applied initially.

Phosphate frequently affects the composition and quality of crops. Phosphates consistently increase the phosphorus composition and sometimes the protein content of alfalfa, the increases being related to the fertility of the soil and the amount of fertilizer applied. Phosphates frequently increase the phosphorus content of the grain and straw of small grains but sometimes decrease the protein content of the grain. Test weight of the grain may be increased slightly. There is no consistent effect of phosphate upon the sucrose content of sugar beets. In Montana the incidence of seedling diseases of beets is reduced. Potato quality and grade are not affected. Neither the staple length, lint percentages, boll size, nor maturity of cotton is influenced.

In Arizona phosphate increases the size and compactness of lettuce heads and hastens the maturity. The grade of peas and tomatoes and the quality of tomato transplants are improved. Phosphate has increased the phosphorus content of leaves of tree fruits.

The low phosphorus content of forages results in phosphorus malnutrition in animals. Such cases of malnutrition are reported from California, Nevada, New Mexico, Oregon, Idaho, Montana, Utah, and North Dakota.

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